Volume 12 FEBRUARY 1928 Number 2

BULLETIN

of the

American Association *of* Petroleum Geologists

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THE BULLETIN

of the

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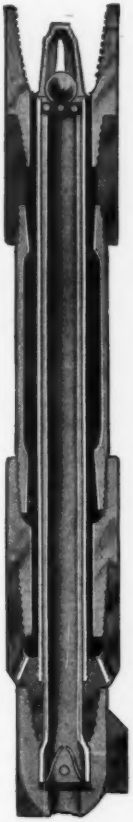

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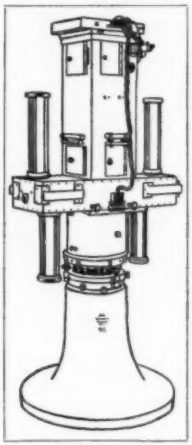

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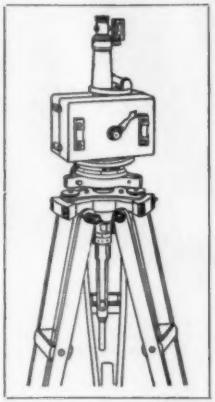

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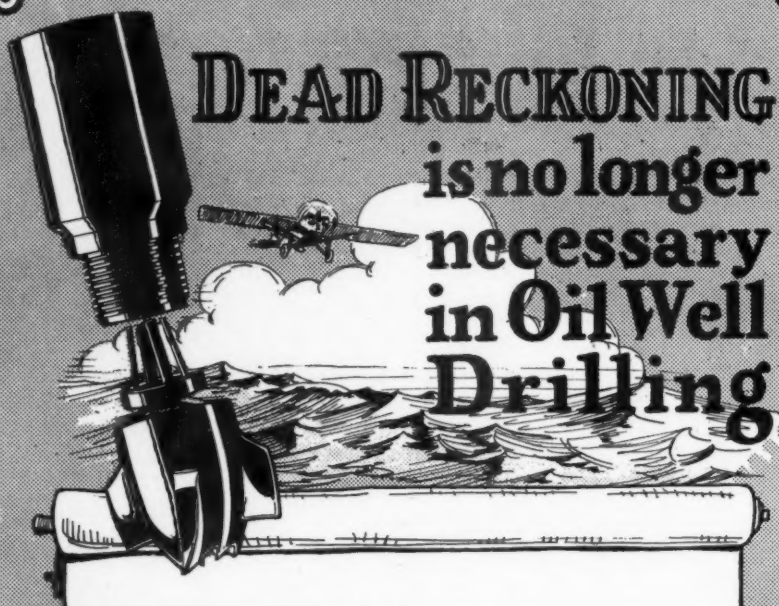

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DIVISIONS AND DURATION OF THE PLEISTOCENE IN SOUTHERN CALIFORNIA[1]

J. E. EATON[2]
Los Angeles, California

ABSTRACT

The maximum known marine sections of the Pleistocene are believed to be in southern California. More than 2,500 feet of lower Pleistocene marine and fossiliferous strata are locally present in Ventura Basin at the top of a 19,832+ foot late Cenozoic section which indicates a conformable deposition of marine strata from some time in the Miocene, through the Pliocene, and into the lower Pleistocene.

The principal deformation and locally profound erosion of the petroliferous horizons, and the chief migration of petroleum into commercial pools, occurred, in southern California, in Pleistocene time. These features are hard to reconcile with any supposed short duration of the epoch.

The Pleistocene record in southern California embraces a lower time interval represented by the deposition of 2,500+ feet of marine strata, a middle time interval involving elevation and the local erosion of as much as 5,000 feet of rocks, and an upper time interval embracing subsidence and minor recovery. This record indicates a duration for the epoch in excess of 1,000,000 years.

It is considered that most of Pleistocene time represents a break in the known stratigraphic succession, and that the lack of an adequate sedimentary record and a failure to appreciate the magnitude of erosional intervals has caused the epoch to be generally underestimated.

It is concluded that the terms Pleistocene and Glacial are not synonymous. The Pleistocene is viewed as having had four major divisions: (1) Lower (Pedroian), characterized by a local deposition of marine sediments; (2) Middle (Sierran), involving elevation and erosion; (3) Upper (Glacial), embracing glacial and inter-glacial erosion on portions of the continents; and (4) Uppermost (Champlain subsidence), recording depression.

The indicated Pleistocene duration in excess of 1,000,000 years, and the evidence

[1]The Pleistocene portion of a paper entitled "The Fernando Group of Southern California," outlined before the Los Angeles meeting of the Pacific Section of the Association on October 29, 1926. Manuscript received by the editor, October 20, 1927.

[2]Consulting geologist, 628 Petroleum Securities Bldg., Los Angeles, California.

of early diastrophism, is believed to simplify the problem of the enormous accumulations of petroleum in California during the epoch.

INTRODUCTION

Various geologists have collected evidence tending to show that the maximum known marine sections of the Pleistocene are in California. The simplest chronology of the epoch is also indicated to be furnished by this territory. Although some individual phases of the Pleistocene are better illustrated in other parts of the world, the range and diversity of the California evidence gives a perspective of the epoch as a whole which is not obtainable in many other localities.

The histories of the Pleistocene and of petroleum are so closely interwoven in California that a discussion of one is to some extent a discussion of the other. In southern California, the principal deformation of the petroliferous strata, and the chief migration of petroleum into commercial pools, occurred in Pleistocene time. This is evidenced by the fact that the lower Pleistocene strata dip, as a rule, almost as steeply as do the Pliocene and upper Miocene oil horizons.

The accumulation of enormous quantities of petroleum during the Pleistocene epoch has presented an interesting problem to California geologists. The most obvious explanation—a long lapse of time after diastrophism—has been slow of acceptance owing to the conceptions, (1) that the epoch was of comparatively short duration, and (2) that the terms Pleistocene and Glacial are more or less synonymous. A key to the problem was furnished about thirty years ago, when pre-Glacial time in the Quaternary period was recognized by Le Conte[1] and Hershey[2]. Evidence was presented to show that the Glacial was an upper division of the Quaternary, and that it was preceded by another division of considerable magnitude involving erosion.

The writer has recently examined in southern California what is probably the maximum known marine section (2,500+ feet) of the Pleistocene series, together with a record of subsequent elevation, erosion, and subsidence. The evidence furnished by this district supports certain conclusions regarding the Quaternary period previously arrived at by Le Conte, Hershey, and others.

The author is indebted to various geologists for much aid. The macrofossils that he has collected have been identified by Arthur J.

[1]Joseph Le Conte, "The Ozarkian [Sierran] and its Significance in Theoretical Geology," *Jour. Geol.*, Vol. VII (1899).

[2]Oscar H. Hershey, "Ozarkian Epoch—a Suggestion," *Science*, n.s., Vol. III (1896), pp. 620-622.

Tieje, and have been in part examined by Ralph Arnold. The microfossils have been identified by Paul P. Goudkoff and Donald D. Hughes from sections furnished them.

The nomenclature to be used follows in general that of the United States Geological Survey, except in the quotations or where new divisions are recognized. The word *fauna*, when unqualified, is used in the sense of *macrofauna*, and refers to marine invertebrates.

FEATURES RELEVANT TO CORRELATION

MAJOR STRUCTURE

A large part of California is located in the Pacific geosynclinal belt, which, during the Cenozoic era, was perhaps the most consistently depressed area of which we have record. This geosynclinal belt does not necessarily separate the Pacific abyss from the American continental area, although it approximately does so, there appearing to be at least locally what Schuchert[1] has called borderlands—structures that lie on the outer (oceanward) side of geosynclines. The highly disturbed nature of the belt demonstrates the law of James Hall that areas of heavy sedimentation are major fold zones, and its faulting bears out Stille's[2] further application of this law.

The area has been, since Jurassic time at least, a zone of crustal weakness lying between stronger segments of the lithosphere. It has been split, as a result, into numerous blocks having various shapes, sizes, elevations, and tiltings. The blocks have been affected not only by simple compression and tension, but also by differential horizontal movements apparently caused by unequal creep of the confining crustal segments. These movements have given the structure prevailing strikes.[3]

A complete marine stratigraphic record between middle Eocene and middle Pleistocene times may eventually be assembled in California. The deepest parts of the Ventura Basin, for instance, record continuous or almost continuous deposition from the middle Eocene into the early Pleistocene, nearly all of which was marine except for certain Oligocene(?) strata. California contains localities where there was apparently no break in sedimentation between some, or all, of the epochs of the

[1]Louis V. Pirsson and Charles Schuchert, *Text-Book of Geology*, Part II (1924), p. 138.

[2]Hans Stille, *Grundfragen der vergleichenden Tektonik*, 1924.

[3]J. E. Eaton, "A Contribution to the Geology of Los Angeles Basin, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 8 (August, 1926), p. 763.

Cenozoic era. This feature implies an enormous thickness of sediments. In California, strata recognized as Eocene aggregate approximately 9,000 feet in thickness; Oligocene(?), 4,000; Miocene and Pliocene[1] (undifferentiated), 18,000; and Pleistocene, 2,500 feet. The Pleistocene sediments above mentioned represent only the lower portion of the epoch.

OTHER FACTORS

In California, where some of the expected erosional intervals are absent, to insist that an unconformity be present in order to separate epochs would locally result in there being no division made in a conformable sedimentary succession covering parts of three epochs. The separation of the Pliocene from the Pleistocene presents perhaps the simplest problem with reference to these conformable successions, for the reason that the contact between the two epochs is marked by a critical period in the faunal life which occurred at the inception of what the writer will term the Quaternary epeirogenic movement, and which is recognizable over wide areas in the state.

Critical periods in the history of the earth have long been recognized as separating the eras. Critical periods of less magnitude probably separate certain geologic periods, and even epochs. Southern California furnishes evidence tending to show: (1) that a critical period in the faunal succession embraces but a fraction of the time occupied by a related epeirogenic movement or regional unconformity; (2) that the more abrupt change in fauna occurs at the *first* distinct change in environment; and (3) that the first distinct change in environment coincides with the inception of a cause, and not with its culmination or maximum stratigraphic effect.

Le Conte[2], while recognizing that faunal unconformities may be occasioned by migrations due to various causes, believed that critical periods were marked by exceptionally rapid steps in evolution, by a fewer number of generations necessary to transform one species into another, and by a rapid extinction of what he called rigid, or specialized forms. He says:

> The generalized forms change, the specialized, die. When the change begins, I imagine, it goes on rapidly until equilibrium is again restored. The change being comparatively rapid is completed in a few generations.

[1]The Miocene and Pliocene series have not been satisfactorily differentiated in parts of California. Different geologists have placed the contact all the way from 16 to 80 per cent above the base of the Neocene, which is 18,000+ feet thick in its maximum sections.

[2]Joseph Le Conte, "Critical Periods in the History of the Earth," *Calif. Univ., Dept. Geol. Bull.*, Vol. I (1895), pp. 313-336.

The crustal blocks in southern California which record a marine contact between the Quaternary and the Tertiary give evidence that a

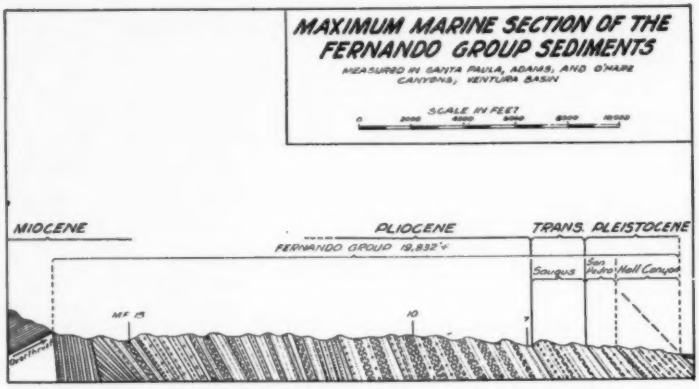

FIG. 1

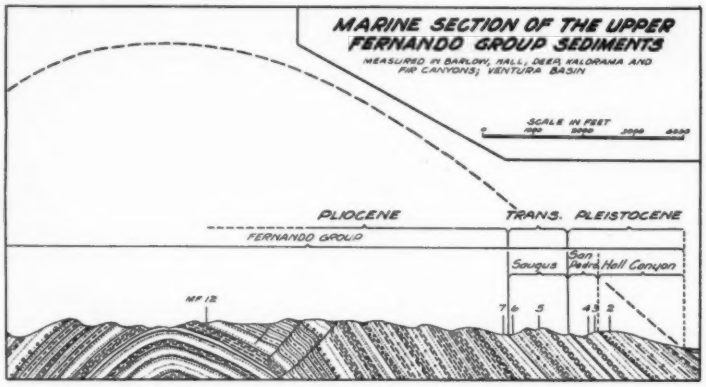

FIG. 2

critical change from Pliocene marine invertebrate faunas 36.3 to 50 per cent extinct, to lower Pleistocene faunas 1.8 to 9 per cent extinct, occurred with extreme rapidity in conformable strata.

EVIDENCE OF AGE

SPECIFIC DETERMINATIONS

The Pleistocene age of various marine strata in southern California was recognized by numerous workers in the latter part of the nineteenth century. The work of Dall[1], in particular, formed a basis for subsequent investigations.

It is upon Arnold's[2] great monograph describing the Pleistocene of San Pedro, however, that the stratigraphy of the marine Pleistocene of southern California chiefly rests. Arnold lists and describes 407 species and varieties of marine invertebrates from the uppermost Pliocene (transition?) and the Pleistocene of California. In the introduction to his monograph, he says:

> Enough evidence was obtained at different points along the coast to warrant the statement that we have in the California deposits the greatest development of the marine Pleistocene in the world. Future investigations are necessary in order to give more accurately the thickness of the sediments deposited and the amount of orogenic movement which has taken place since the beginning of the Pleistocene epoch.

Arnold realized that the type locality of the San Pedro *series* exposes only small fragments of the marine Pleistocene succession of California. He recognized Pleistocene sediments as occurring at depths between 920 and 1,320 feet in a well in central Los Angeles Basin, and also in a surface section in Ventura Basin "at least" 1,000 feet thick.

EVIDENCE OF THE CRITICAL PERIOD

Owing to the rapid subsidence of several of the California geosynclinal blocks, the first shock of the Quaternary epeirogenic movement was insufficient to overcome their tendency toward depression. These areas therefore reveal a marine contact between the Pliocene and the Pleistocene, the critical nature of which is shown on widely separated blocks.

In the abnormally deep Ventura Basin, in southern California, sedimentation was continuous between the two epochs in the west. In the undoubted Pliocene on this block, at least 6,000 feet thick, the identified faunas are from 36.3 to 50 per cent extinct. In the lower 800 feet of the undoubted Pleistocene, the identified faunas are from

[1]W. H. Dall, "North American Tertiary Horizons," *U. S. Geol. Survey, 18th Ann. Rep.*, Part II (1898); and in other publications.

[2]Ralph Arnold, "The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Calif. Acad. Sci. Mem.*, Vol. III (1903), pp. 1-420, pl. I-XXVII.

1.8 to 7.4 per cent extinct. The change from a high to a low percentage of extinction occurs rapidly, most of it within less than 100 feet of conformable strata.

In middle California, 300 miles northwest of Ventura Basin, the crustal block exposing the type section of the Merced sediments shows a similar relation. Lawson[1] gives the measured thickness of the type Merced as being 5,834 feet, and states the section to be "ideally simple." The type section is very sharply divided into two faunal successions. Dall[2] has said of this region:

> The upper part of the beds included in the Merced series at the typical locality has a fauna in which few if any extinct species were detected by the writer during an examination of the section in September, 1897. The impression derived from this examination was that this portion of the Merced series is probably Pleistocene, though strictly conformable with the lower beds.

Martin[3], who made a later study of the locality, divides the type section into a lower portion having faunas which average 50 per cent extinct, and an upper portion having faunas in which no species is extinct. He says:

> Ralph Arnold has referred this upper Merced to the Pleistocene age, while the greater portion of the Merced, stratigraphically underlying it, has been placed in the preceding period. From the faunal relations there seems to be little doubt that Arnold's determination is approximately correct. The close resemblance between the Recent fauna and that of the upper Merced seems to suggest the possibility of there being a break between the upper and lower Merced which cannot be accounted for merely by the depositional record.

The break noted by Dall, Arnold, and Martin, and not accounted for by the depositional record, is apparently the critical period which divides the Pleistocene from the Pliocene, and the Quaternary from the Tertiary. The marine invertebrate faunas of California assumed a modern aspect near the beginning of Pleistocene time, and changed comparatively slowly during the balance of the epoch.

SUMMARY

The contact between the Pliocene and the Pleistocene in California coincides with a critical period in the faunal succession. This critical

[1]A. C. Lawson, "The Post-Pliocene Diastrophism of the Coast of Southern California," *Calif. Univ. Dept. Geol. Bull.*, Vol. I (1893).

[2]*Op. cit.*, p. 337.

[3]Bruce Martin, "The Pliocene of Middle and Northern California," *Calif. Univ. Dept. Geol. Bull.*, No. 15, Vol. IX (1916).

period was the result of a tremendous shock—the first shudder of a great epeirogenic movement which was to raise most continental areas of the world well above the strand line, and was to all but obliterate the littoral record of life between lowermost and uppermost Pleistocene time. It is the sudden and permanent change in fauna to a modern aspect, occurring near the inception of the Quaternary epeirogenic movement and simultaneously upon every recording crustal block, that marks the beginning of the Pleistocene in California.

THE PLEISTOCENE SUCCESSION IN SOUTHERN CALIFORNIA

Figure 1 illustrates the maximum marine section 19,832+ feet in thickness, of the Fernando group sediments of southern California. This section contains the maximum known marine succession of the Pleistocene series. The section was measured on the Santa Paula monocline, in Santa Paula, Adams, and O'Hare canyons, Ventura Basin. The formation thicknesses which are given refer to this locality.

Figure 2 illustrates a thinner but more fossiliferous section of the upper Fernando group sediments. This section was measured about 10 miles farther southwest, on the Ventura Avenue anticline, in Barlow, Hall, Deep, Kalorama, and Fir canyons, Ventura Basin. The strata here are finer-grained and approximately 35 per cent thinner than in the maximum section.

Figure 3 illustrates the indicated correlation of the Pleistocene in a part of southern California.

Figure 6 presents an ideal graph of the Quaternary epeirogenic movement in North America.

CONDITIONS UNDER WHICH THE LOWER PLEISTOCENE SERIES WAS DEPOSITED

The lower Pleistocene series of southern California forms the upper part of the Fernando group sediments, which latter were defined by Eldridge and Arnold[1] in the first published description, as follows:

> The rocks that have received the name Fernando consist of an enormous succession of conglomerates, sandstones, and arenaceous clays, largely of the Pliocene age, developed over considerable portions of southern California. Fossils collected at many localities and at many horizons throughout the formation indicate that it extends from the Upper Miocene (San Pablo formation of the general geologic column of the State) well up in the Pleistocene (San Pedro formation).

[1]George H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills, and Los Angeles Oil Districts, Southern California," *U. S. Geol. Survey Bull. 309* (1907), p. 22.

The San Pedro formation has in the past been placed above the Fernando group by some geologists, including the writer. The maximum marine sections (Figs. 1 and 2) now corroborate the first pub-

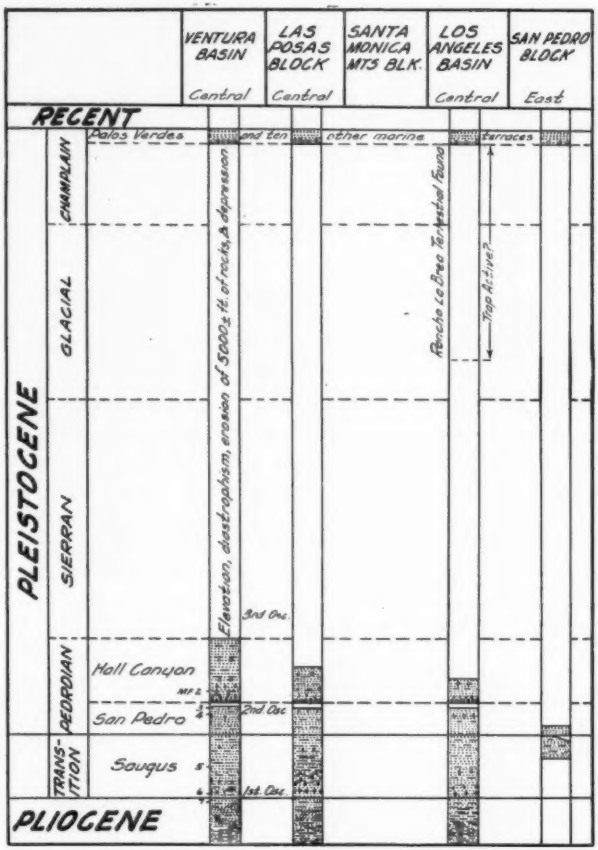

FIG. 3

lished definition of the Fernando, and should obviate further discrepancies.

The Fernando group sediments were deposited in a sea which

encroached with occasional hesitations, and also very rapid steps, over the uneven surfaces of dissimilar crustal blocks in southern California. These sediments seem to be conformable in the very deepest parts of certain basins from their base to their top. On the edges of these basins, the lowest stratum of the Fernando sediments which is locally present may represent, due to overlap, any horizon in the 19,832+ feet of strata present in the maximum section. Local unconformities apparently occur on the fringe of these basins between 6 divisions of the group, but in every case these disappear basinward into conglomerates or sands recording shallow-water conditions—but not complete emergence. Recent work indicates that the unconformity reported by Kew[1] and by the present writer[2] on basin edges between the Saugus and underlying formations does not extend to the deepest parts of Ventura and Los Angeles basins.

The Ventura Basin crustal block subsided more persistently than did any other part of southern California during the Cenozoic era. Sedimentation was probably continuous in the very deepest parts of the basin from some time in the Eocene until the close of the lower Pleistocene.[3] This particular subsidence is recorded by the presence of approximately 30,000 feet of Cenozoic strata. The subsidence of western Ventura Basin was not stopped by the first shock of the Quaternary epeirogenic movement. A second and stronger shock raised parts of the basin slightly above sea-level, but the effect of this was soon overcome. At a third and still stronger shock, Ventura Basin, in common with every other crustal block in California, rose above sea-level, and appears to have remained emergent until near the end of Pleistocene time.

UPPER PLIOCENE SERIES

Pliocene time in southern California was marked by further encroachment of the Fernando sea, and the laying down of fossiliferous conglomerates and sands over wide areas. In the upper part of the Pliocene, as much as 4,000 feet of bluish-gray shaly sands and grayish-blue clays were deposited in the deeper portions of Ventura Basin.

[1]William S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924).

[2]*Op. cit.*

[3]Local unconformity in the Miocene is pronounced on some edges of Ventura Basin. There are indications, however, that a composite sedimentary section may be assembled in the basin which will show the Tertiary and lowest Quaternary succession complete except for a portion of the Eocene.

These sediments contain occasional lenses of gravel, and better-bedded sand layers from a fraction of an inch to several feet in thickness. This period of sedimentation was brought to a close by a coarsening of the sands in the upper few hundred feet of the Pliocene series. The uppermost 60 feet of the Pliocene has yielded the characteristic fauna, 36.3 per cent extinct, listed in Table I as horizon MF 7.

PLIOCENE-PLEISTOCENE TRANSITION ZONE

Saugus formation (*1750± feet*) The inception of the Quaternary epeirogenic movement was marked in southern California by a short, but sharp, oscillation. Western Ventura Basin paused momentarily in its age-long subsidence, as is evidenced by the occurrence of more sandy and better-bedded strata in the uppermost Pliocene beds, and the flourishing

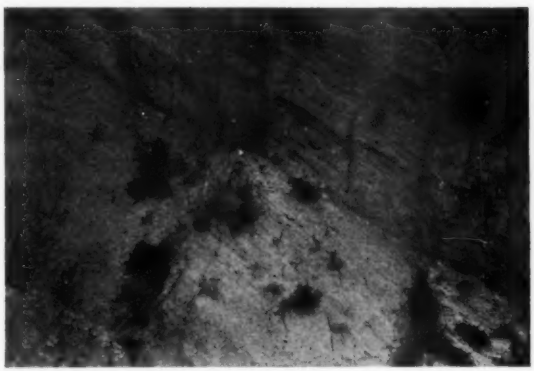

FIG. 4.—Contact between the Pliocene and the transition sediments in western Ventura Basin, showing conformable gradation. A part of horizon MF 7 is visible on the lower left, and a part of horizon MF 6 on the upper right. First oscillation. Exposure 50 feet. Photographed by the author in Contact Canyon.

of a last Pliocene fauna. Reflex action quickly caused subsidence to be resumed, and the Fernando sea encroached farther on various crustal blocks. The basal Saugus (transition) sediments were then laid down.

The Saugus sediments range from ferruginous clays and shaly sands in the deepest areas, to sands and gravels nearer shore. The prevailing basal stratigraphy is one or more thin, hard, calcareous sandstones which fracture into rectangular slabs, these being overlain

by some 50 feet of heavy-bedded soft sand, followed in turn by loose lavendar-hued conglomerate and soft sandstones. *Dendraster diegoensis venturaensis* Kew, a guide fossil apparently restricted to these lower beds, is commonly present in the marine areas. The Saugus formation is entirely marine in western Ventura Basin, but it grades eastward into strata which are only partly marine. The main body of the Saugus is composed, in the marine areas, of fairly well-bedded fine and medium-grained shaly sand, predominantly yellow in color, but carrying purer gray, and more impure bluish, sands. Conglomerates are rare or plentiful according to the locality. The Saugus is commonly much coarser in texture in brackish-water areas farther east.

Although edges of the basin on the east record an unconformity, this succession is obviously conformable with the Pliocene strata in western Ventura Basin. Minor scouring by currents occurred locally, but the uppermost Pliocene faunal horizon, 60 feet thick, is there overlain for 14 miles by basal Saugus beds without appearing to be anywhere cut out. The contact is, moreover, well exposed in at least three localities where it appears to be conformable.

The critical change in life occurred sharply at the base of the Saugus, whether in fairly deep or in shallow water, in fine-grained or in coarse material. The more characteristic species of horizons MF 6 and 7 are found together in only about 40 feet of strata. The change in lithology is locally very noticeable, but similar changes were present during parts of Pliocene time, and yet the faunal change in the basal 100 feet of the transition zone was greater than that in 6,000 or more feet of Pliocene strata. The extinct Pliocene forms are, moreover, most often found in southern California in those Pliocene beds whose lithology and depth of deposition resembled that of the post-Pliocene sediments. The saline relations did not vary materially in western Ventura Basin, for there were no large rivers in that locality, and on the whole there was an open sea. There appears to have been a change to cooler waters, but the upper faunas of the San Pedro formation which followed a short time later show warm-water conditions, and yet the characteristic Pliocene species did not reappear. The writer considers that none of the features discussed completely explains the permanent change in life in conformable strata which occurred here and elsewhere in California at the beginning of the Pleistocene.

LOWER PLEISTOCENE SERIES (PEDROIAN)

San Pedro formation[1] (*800 ± feet*).—The San Pedro formation or lower San Pedro *series* includes, in Ventura Basin, strata at its base which resemble those at the typical locality on the San Pedro crustal block. Above these beds are overlying and apparently conformable strata, eroded at the typical locality, which contain warmer and more modern faunas than are present at the type. The upper or additional strata in Ventura Basin represent a small part of the enormous interval of erosion which separates the San Pedro and Palos Verdes formations at the typical locality (Fig. 3, right). The formation is entirely marine in western Ventura Basin, but it grades eastward into non-marine strata.

The San Pedro formation grades up from the Saugus formation in the deeper parts of Ventura and Los Angeles basins in a manner that makes the precise contact difficult to ascertain. The correct contact in Ventura Basin may be somewhat lower than has been drawn by the writer. The formation is composed chiefly of medium-grained gray sands, which alternate with thinner, fine-grained, and more shaly sands of a yellow color. Several comparatively pure, white, pebbly sand layers are commonly present, and a few lenses of gravel occur.

The sediments in Ventura Basin are correlated with the formation at the typical locality because (1) practically all of the macroscopic species found in the former appear to be present in the type fauna; (2) the general succession is at both localities locally conformable with underlying sediments which are transitional from the Pliocene; (3) both contain faunas which are warmer than those of the underlying transitional sediments; and (4) both have a similar and fairly distinctive lithology which grades up from the transitional beds. The typical cool-water horizon at San Pedro is believed to be represented in Ventura Basin by gray sands which occur below the warm-water horizons.

Arnold has listed in his monograph a fauna of 265 species and varieties from the basal San Pedro sediments at the typical locality. He tentatively listed this fauna as being 12.5 per cent extinct, but from our present knowledge of living forms we now know that the extinction is less than 9 per cent. The lower Pleistocene faunas reported from Ventura Basin are 7.4 per cent or less extinct, the two faunas listed by Arnold from that district being 1.8 and 4 per cent respectively. The thin, cool-water horizon at the typical locality of the San Pedro

[1]The lower San Pedro *series* of the typical locality, named the San Pedro formation by W. S. W. Kew in unpublished manuscript.

formation is almost certainly stratigraphically lower than the horizon listed as MF 4 in Ventura Basin. Arnold states in his monograph (p. 66) that the typical horizon represents one which is transitional to warmer conditions. This conclusion is concurred in by the writer, for the upper part of the San Pedro formation sediments in Ventura Basin, eroded at the typical locality, were laid down in fairly warm water.

Arnold tentatively correlated the Barlow Ranch beds, equivalent to horizon MF 4, with the upper San Pedro *series* or Palos Verdes formation of the typical locality, principally on the basis of both having warm-water aspects. The field work of the present writer indicates that these two successions do not occur at the same horizon. The sediments in Ventura Basin are near the base of the Pleistocene, have everywhere an appreciable dip, and were laid down prior to the Pleistocene erosion of as much as 5,000 feet of rocks (Fig. 2). The typical sediments of the upper San Pedro *series* or Palos Verdes formation are near the top of the Pleistocene, form a marine terrace horizontal except near recent faulting, and were laid down on truncated lower Pleistocene strata subsequent to the great interval of erosion (Fig. 3).

Hall Canyon formation (1,800± feet).—The warm-water Hall Canyon formation of Ventura Basin represents another small portion of the long interval of erosion which occurred between the San Pedro and Palos Verdes formations at the typical locality of the two latter successions. The Hall Canyon sediments of Ventura Basin may be in part equivalent to somewhat similar sediments which outcrop with an appreciable dip on Los Cerritos Hill in Los Angeles Basin. In the absence of definite data bearing on their correlation, the writer describes the strata under the name of the canyon in Ventura Basin where they are best exposed. They are almost entirely marine in western Ventura Basin, but the reverse is true in areas farther east.

The Hall Canyon formation is separated from the underlying San Pedro formation in some deeper parts of Ventura Basin by a very minor diastem only, but in other localities an unconformity is present which causes it to rest upon the San Pedro formation with an angular discordance. This unconformity records the second oscillation of the Quaternary epeirogenic movement, which raised some portions of Ventura Basin definitely above sea-level for the first time since the Miocene, or, possibly, since the Eocene. The interval of local erosion was comparatively short, however, and reflex action soon caused deposition to be resumed. The Hall Canyon sediments were then deposited.

The Hall Canyon formation has a characteristic lithology in much of southern California. It is composed chiefly of fine-grained yellow shaly sand, poorly bedded and poorly consolidated, with minor gray sand layers. Lenses of gravel are scattered throughout the succession, and these commonly make up a large proportion of the basal sediments. The sediments are rather coarse in non-marine areas on the east, and there weather to orange and reddish tints. The lithology

FIG. 5.—Contact between Hall Canyon gravels and gray sands of the San Pedro formation in western Ventura Basin, showing local unconformity. Second oscillation. Exposure 8 feet. Photographed by the author in Hall Canyon.

of the Hall Canyon formation is in general so different from that of the San Pedro formation that the contact between the two successions can usually be ascertained, in Ventura Basin, even where poorly exposed.

Although occurring after a disturbance more severe than that which caused the critical change in life between the Pliocene and the transition sediments, the warm-water faunas of the Hall Canyon formation are very similar to the upper or warm-water faunas of the underlying San Pedro formation, apparently because the more specialized species had already been eliminated.

The macrofossils listed in Table I have been collected by the writer in western Ventura Basin, and have been identified by A. J. Tieje. Dr. Tieje reports horizons MF 2, 3, and 4 as having warmer and more modern aspects than those of the typical San Pedro formation sediments. This is in accord with the field work, which places the thin

TABLE I

	Pleistocene			Transition		Plio-cene
	Hall Canyon	San Pedro		Saugus		
	MF 2	MF 3	MF 4	MF 5	MF 6	MF 7
Extinction	3.8	4.3	7.4	11.8	8.3	36.3
PELECYPODA						
Anomia peruviana Orbigny	x		x			
Arca cf. camuloensis Osmont						x
Cardium quadrigenarium Conrad				x		x
Cardium quadrigenarium fernandoensis Arnold						x
Chama exogyra Conrad	x		x			
Chione cf. elsmerensis English						x
Chione fernandoensis English						x
Cryptomya californica Conrad	x		x		x	
Leda taphria Dall	x			x	x	
Macoma nasuta Conrad	x	x	x	x		x
Macoma sp.		x			x	x
Marcia subdiaphana Carpenter						x
Modiola cf. flabellata Gould (*M. recta* of authors?)						x
Ostria lurida Carpenter			x			
Paphia staminea Conrad	x					
Paphia cf. tenerrima Carpenter				x		
Pecten circularis aequisulcatus Carpenter		x				
Pecten hastatus Sowerby						x
Pecten cf. healeyi Arnold						x
Pecten latiauritus Conrad	x	x	x			
Pecten, two sp.						x
Pododesmus (*Monia*) *macroschisma* Deshayes			x			x
Saxidomus nuttallii Conrad					x	x

TABLE 1—*Continued*

	Pleistocene			Transition		Pliocene
	Hall Canyon	San Pedro		Saugus		
	MF 2	MF 3	MF 4	MF 5	MF 6	MF 7
Extinction	3.8	4.3	7.4	11.8	8.3	36.3
Schizothaerus nuttallii Conrad	x	x				
Semele decisa Conrad			x			
Solen sicarius Gould						x
Solen sp.					x	
Tereda sp.						x
GASTROPODA						
Acanthina (Acanthinucella) spirata Blainville	x	x				x
Actaeocina culcitella Gould			x			
Alectrion (Schizopyga) californiana Conrad			x		x	
Alectrion (S.) cooperi Forbes	x	x	x	x		
Alectrion (S.) fossata Gould	x	x	x	x	x	
Alectrion (S.) mendica Gould	x		x			x
Alectrion (S.) perpinguis Hinds	x	x	x		x	
Antiplanes perversa Dall						x
Calliostoma gemmulatum Carpenter	x					
Cancellaria tritonidea Gabb			x	x		x
Chlorostoma funebrale A. Adams	x	x				
Columbella (Alia) gausapata Gould		x	x			
Conus californicus Hinds		x		x		
Crepidula excavata Broderip		x				
Crepidula grandis Middendorf					x	x
Crepidula onyx Sowerby			x			
Crucibulum spinosum Sowerby			x			
Cryptoconus carpenteriana fernandoana Arnold						x

TABLE 1—*Continued*

	Pleistocene			Transition		Pliocene
	Hall Canyon	San Pedro		Saugus		
	MF 2	MF 3	MF 4	MF 5	MF 6	MF 7
Extinction	3.8	4.3	7.4	11.8	8.3	36.3
Cryptoconus tryonianus Stearns				x		
Cymatosyrinx (Elaeocyma) hemphilli Stearns		x	x			
Eulima (Melanella) micans Carpenter		x				
Fusinus monksae Dall	x					
Fusinus sp.						x
Ianacus nummarius Gould	x					
Lacuna compacta Carpenter		x				
Mangilia cf. angulata Conrad	x					
Mangilia sp.	x		x			
Monoliopsis incisa ophioderma Dall	x	x	x			
Neverita recluziana Deshayes	x	x	x	x	x	
Neverita recluziana alta Dall	x		x			
Neverita sp.						x
Nucella emarginata Deshayes				x		
Odostomia, two sp. (?)		x				
Olivella biplicata Sowerby	x	x	x	x	x	
Olivella pedroana Conrad		x	x			
Olivella cf. pedroana Conrad	x					
Olivella sp.			x			
Pseudomelatoma torosa Carpenter				x		
Strioterebrum pedroanum Dall	x	x	x			
Triremis festiva Hinds			x			
Tritonalia foveolata Hinds		x				
Turbonilla sp.	x	x	x	x		
Turritella cooperi Carpenter				x	x	x

TABLE 1—*Continued*

	Pleistocene			Transition		Pliocene
	Hall Canyon	San Pedro		Saugus		
	MF 2	MF 3	MF 4	MF 5	MF 6	MF 7
Extinction	3.8	4.3	7.4	11.8	8.3	36.3
Turritella jewettii Carpenter				x	x	
Turritella, n. sp.						x
CRUSTACEA						
Balanus concavus Bronn	x	x				x
ECHINOIDEA						
Dendraster diegoensis venturaensis Kew					x	
Dendraster excentricus Eschscholtz				x		
SCAPHOPODA						
Dentalium pseudohexagonum Dall	x	x	x	x		
Dentalium sp.						x

typical horizon of the San Pedro formation (lower San Pedro *series*), in gray sands below horizon MF 4.

MIDDLE PLEISTOCENE (SIERRAN)

The long interval of Quaternary erosion in North America which apparently preceded the invasion of the first ice sheet, was given the name Ozarkian by Hershey[1] in 1896. The term was soon found to be in conflict with one designating a Paleozoic formation, whereupon Le Conte[2] in 1899 proposed that the term Sierran be substituted should a new name become necessary. The term Sierran, as it is used herein, designates an interval of elevation and erosion above lower Pleistocene marine horizons of record, and below the first ice sheet or its indicated equivalent.

[1] *Op. cit.*

[2] Joseph Le Conte, "The Ozarkian [Sierran] and its Significance in Theoretical Geology," *Jour. Geol.*, Vol. VII (1899).

The significance of the Sierran was first recognized by Le Conte. His description of the interval is so applicable to the present discussion that it is quoted at length, as follows:

> By continued reflection on the enormous changes that occurred in the western part of the continent at the end of the Tertiary, I have been led to recognize the existence of an epoch of long duration and of great importance immediately preceding the time of the invasion of the ice sheet. On account of its great importance this epoch certainly deserves a distinctive name.....
>
> The epoch was first recognized by Hilgard and more distinctly by McGee, as the post-Lafayette uplift, shown by extensive erosion of the Lafayette gravels all over the southern states.....Upham....refers it to the early Quaternary, but advances it to a *primary* division of that period comparable with the Glacial. But even yet, it seems to me, its full importance is scarcely recognized unless it be by McGee, and its true significance entirely overlooked. Indeed both its importance and its significance are brought out in strong relief only by the study of its phenomena in the western part of the continent and especially in California.
>
> If with Upham we divide the Quaternary period into three epochs, the Ozarkian [Sierran], the Glacial, and the Champlain, then the Ozarkian was by far the longest, in fact, longer than both the others put together..... In many ways the Ozarkian is strongly contrasted with the other epochs of the Quaternary. If, for example, we adopt the division into three epochs, these are characterized each in its peculiar way: the first, by elevation; the second, by ice accumulation; the third, by depression; the first, by immense erosion; the second, by glaciation and drift deposit; the third, by stratified deposits in seas and lakes.
>
> The Ozarkian.....being a period of continental elevation and enlargement, it has left no strata exposed to view.....So far as stratified rocks and fossils are concerned, this is a period of lost record—it is a *lost interval*....
>
> In the eastern part of the continent, the work of erosion of this time is seen in the so-called old river-beds deeply underlying the present beds and extending beyond their limits on each side, and especially continuing beyond the limits of the present continent, as submerged channels trenching the submerged continental shelf, notching deeply its margin and opening out into the abyssal waters of the true oceanic basin. It is shown not only in the deep gorges of the Ozark region, not only in the deep and widespread erosion of the Lafayette gravels in the south, but also in the highly emphasized topography underlying the drift all over the glaciated region of the north. By means of the submerged channels the amount of vertical elevation of the eastern portion of the continent has been estimated as certainly not less than 3,000-5,000 feet and may have been much greater. Similar evidences of elevation are found on the Pacific coast and also on the coasts of Europe and of Africa. We have every reason to believe that it was a time of almost universal continental elevation and enlargement.

Sierran time began, in southern California, with the third oscillation of the Quaternary epeirogenic movement. California appears to

have been raised by this oscillation completely above sea-level. The crustal oscillations of Sierran time have not been differentiated from one another in California, due to erosion, but it seems probable that they formed a sequence of ascending severity such as characterized the first three oscillations recorded by the marine succession.

Sierran time reveals, in California, some of the grandest structural effects recorded in the Cenozoic era. The Pacific geosynclinal belt, with its prodigious thickness of sediments, was crushed between comparatively rigid segments of the lithosphere, and was shattered in such a manner that much of the resulting geology is complex and difficult to unravel. The larger blocks formed buffers and suffered the least deformation, but they were split by many faults along which differential horizontal movement caused much of the structure now yielding petroleum to be formed.

The smaller blocks were caught between the larger ones and were severely deformed. Ventura Basin was overridden from the north and south, and was split into fragments. The 19,832+ foot section shown in Figure 1 was possibly tilted almost to its present inclination, and the strata farther west shown in Figure 2 were folded into a steeply dipping anticline. North and east of these sections, considerable overthrusting occurred. On the east, Miocene strata were locally thrust over Pliocene sediments for a distance estimated to be 3½ miles. On

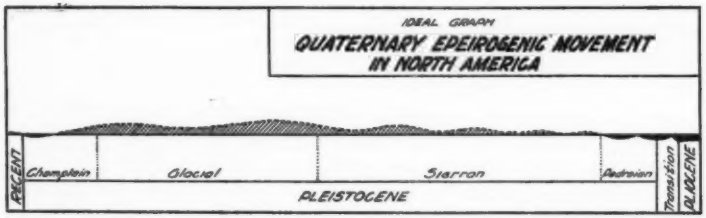

FIG. 6

the north, a series of overthrusts reversed the stratigraphic sequence, for Miocene rests on Pliocene, Oligocene(?) on Miocene, and Eocene on Oligocene(?), with Eocene locally overthrust on Pliocene and cutting out the intervening series. The foregoing may give some idea of the Sierran deformation of parts of California, of the forces which caused

most of the structure now yielding petroleum to be formed, and of why California strata locally have extremely high dips.

The chief folding occurred in the Pacific geosynclinal belt, but the elevation appears to have been universal. East of California, the Grand Canyon district was raised vertically several thousand feet, was fractured, and the inner gorge of the Grand Canyon of the Colorado, 3,000 feet deep, was cut. This is known from the work of Dutton,[1] who says:

> The last great upheaval, exceeding in amount 3,000 feet, was of comparatively recent occurrence, and the river has not yet reached the new equilibrium of action and the new adjustment of its energy to the work of simple transportation.

The peneplained Sierra Nevada mountain range in California was re-elevated at this time along its eastern side, and new stream channels from 3,000 to 6,000 feet in depth have since been locally eroded. The evidence of this is given by Le Conte, who named the Sierran interval from this district.

The conclusion of various geologists that an enormous and underestimated erosive interval occurred in the Quaternary period is corroborated by the maximum marine sections of the Pleistocene in California. The section illustrated in Figure 2 is unusually simple. It reveals 5,000 feet of Quaternary degradation, and shows that the great interval of post-Tertiary erosion occurred within the Pleistocene epoch. Similar evidence is afforded by the typical Merced sediments of middle California.

UPPER PLEISTOCENE (GLACIAL)

Pleistocene glaciation of parts of middle and northern California is known from the work of Blake, Le Conte, McGee, Muir, Russell, Turner, Lindgren, Hershey, Lawson, Andrews, Holway, Manson, and Matthes. Pleistocene glaciation in the San Bernardino range of southern California is reported by Fairbanks, Carey, and Vaughn. The known Pleistocene glaciation in California is confined to the more highly elevated areas, and has a southern limit of 34° N. Lat. The rather low latitude of much of the state aided in keeping the valleys free from ice sheets, but prevailing temperate winds from the Pacific Ocean were probably also a factor.

[1] Clarence Edward Dutton, "The Physical Geology of the Grand Canyon District," *U. S. Geol. Survey, Second Ann. Rept.* (1882).

The first Pleistocene glaciation in California evidently occurred late in the general event of Quaternary diastrophism, elevation, and erosion. The glaciation of the Sierra Nevada range is reported by Le Conte as subsequent to the principal degradation during the Quaternary period, and widespread deformation of Pleistocene age elevated portions of the state prior to their being glaciated. Considerable time must have elapsed between the deposition of the youngest warm-water lower Pleistocene marine sediments and the last of the enormous erosion which is known to have preceded the first ice.

The chronological position in the Pleistocene of California glaciation is rather definitely placed by the long interval of Sierran erosion, for this occurred below the first glaciation and above the lower Pleistocene marine sediments. Although this erosive interval merges, as a rule, insensibly into the overlying and underlying divisions, its peculiar magnitude and universal extent make it, on the whole, a chronological marker of the first importance.

The last glaciation in California was terminated by a distinct depression of the state, well evidenced but of disputed amount, which will be discussed later.

Terrestrial fauna at Rancho La Brea.—The asphalt beds at Rancho La Brea, in Los Angeles Basin, southern California, have furnished some interesting collections of Pleistocene mammals and birds. These beds, whose fossil life has been described by Merriam[1] and others, consist of gently dipping or possibly almost horizontal alluvial deposits 30 or more feet in thickness, which overlie steeply dipping beds of undetermined age. They are impregnated with viscous tar which has escaped from underlying strata through faulting. It was this tar that trapped, in upper and probably uppermost Pleistocene time, many sabre-tooth tigers, mammoths, camels, wolves, horses, etc., and innumerable birds. Chester Stock[2] informs the writer that:

> The number of mammalian species recognized at Rancho La Brea totals about 39. Of this number about 18 have been recognized as extinct or distinct from living forms.....
>
> It appears to me quite probable that the fauna should be placed somewhere in the last half rather than in the first half of the Pleistocene.

[1]John C. Merriam, "The Fauna of Rancho La Brea," *Calif. Univ. Mem.*, Vol. I (1911-12), pp. 197-272; and in other publications.

[2]Personal communication, May 14, 1927.

The terrestrial fauna of Rancho La Brea is viewed by the present writer as being probably upper and uppermost Pleistocene in age for the reason that it seems to be later than the main Pleistocene diastrophic action. The asphalt beds form extensive sheets above steeply inclined strata deformed chiefly by Sierran movement. The fossiliferous beds do not appear to have been removed or cut out to any large extent by erosion, whereas the lower Pleistocene marine strata of southern California are nearly everywhere much eroded, and have few gently sloping or horizontal layers such as these alluvial deposits. The strongest evidence that the species are younger than middle Pleistocene is, perhaps, that the oils in which they were trapped were apparently collected after Sierran diastrophism had formed or emphasized the underlying anticline. The very existence of an extensive trap would therefore indicate that the forms lived subsequent to a large part at least of the Pleistocene deformation. The same evidence is furnished by the faulting which allowed the oils to rise to the surface from the true oil sands far below. It seems probable that the trap was operative over a rather wide spread of time.

UPPERMOST PLEISTOCENE (CHAMPLAIN SUBSIDENCE)

A pronounced depression of the California coast took place in the uppermost Pleistocene, and was followed by a partial recovery in elevation in recent time. These events are herein correlated approximately with the Champlain subsidence of eastern North America for the reason that the general phenomena are not only similar at both localities, but occur in both areas near the top of the Pleistocene, and follow the same chronological order in the epoch.

The low levels of depression in California are known from a series of 11 or more marine terraces which occur along the coast at elevations ranging up to 1,200 feet above the present sea-level.

Palos Verdes formation[1] (*50 ± feet*).—The lowest of eleven or more horizontal marine terraces in southern California which were laid down during the uppermost Pleistocene depression, is so young that it can still be found at a rather uniform elevation from 40 to 80 feet along much of the coast. This lowest terrace embraces the Palos Verdes

[1]The upper San Pedro *series* of the typical locality, named the Palos Verdes formation by W. S. W. Kew in unpublished manuscript. The present writer uses the term Palos Verdes for purposes of uniform nomenclature, under the impression that it has been applied only to terrace deposits which include, and correlate with, the upper San Pedro *series* of the typical locality.

formation (upper San Pedro *series*) at San Pedro. The formation has not been studied by the writer in Ventura Basin further than to indicate that it is there represented by one of numerous terrace deposits.

Arnold listed in his monograph a warm-water fauna of 292 species and varieties from "the San Pedro terrace" at its typical locality. Because of the many new forms, this fauna was tentatively listed as being 9.5 per cent extinct, but as Arnold expected (p. 29), many of the new forms which gave an appearance of high extinction have since been reported as living. Arnold correlated horizontal beds occurring along the coast at Long Beach and at Newport Beach with the San Pedro terrace, and also included in this correlation deformed beds on Los Cerritos Hill which the writer is inclined to consider lower Pleistocene in age, and more nearly related to the Hall Canyon sediments.

The Palos Verdes terrace formation is composed chiefly of unconsolidated sands and irregular gravel beds. The basal strata at the typical locality (at San Pedro) contain minor gray sand layers re-deposited from the underlying San Pedro formation of lower Pleistocene age. The Palos Verdes beds retain their position in the general series of marine terraces wherever the writer has traced them. They form an almost horizontal sheet over coastal Los Angeles Basin, an edge of which is exposed along the cliffs at or near Long Beach, Seal Beach, Huntington Beach, and Newport Beach. The beds have locally been removed by Recent erosion.

Phenomena on the continental shelf.—Subsidence much greater than the 1,200 feet recorded by the eleven marine terraces in California may have occurred, but the evidence regarding this is not considered to be conclusive. Remarkable submarine canyons, resembling drowned valleys, occur on the continental shelf along the coast of California. Some of these can be traced to depths of 9,000 or more feet below the present sea-level. The interpretation of these canyons, and that of prominent submarine terraces at various levels, has long been a matter of dispute. If they are a measure of late Pleistocene subsidence, California had a very high elevation during parts of Glacial time. Spencer[1] has called attention to similar submarine valleys from 12,000 to 15,000 feet in depth off the eastern and southern coasts of North America.

[1] J. W. Spencer, "Reconstruction of the Antillean Continent," *Bull. Geol. Soc. Amer.*, Vol. VI (1895). Also "Submarine Valleys off the American Coast and in the North Atlantic," Vol. XIV (1903).

INDICATED DURATION OF THE PLEISTOCENE EPOCH

Most of the earlier estimates regarding the duration of the Pleistocene were necessarily based on that portion of the epoch characterized by ice sheets, and could not take into consideration the long period of prior erosion in the Quaternary later reported by Le Conte, Hershey and others. The deep geosynclinal area of southern California now reveals the basal contact of the Pleistocene in marine strata, together with a comparatively simple record of deposition and subsequent erosion from which the duration of the epoch as a whole can be more easily calculated.

The section shown in Figure 2 is taken on a line which illustrates the average dip of the Pleistocene in the district, but the higher dips of the Pliocene which are shown are due to local overthrusting, and are steeper than those which prevail in the average canyon. There is very little difference in the average dip of the Pleistocene and of the Pliocene in the general area. This being the case, it follows that both the Pleistocene and the Pliocene strata shown evidently were lying almost horizontal at the close of the lower Pleistocene, and that the amount of subsequent erosion suggested by the arched line is approximately correct. Under the circumstances, exceptional conditions would have to be postulated in order to reduce materially the inferred amount of Pleistocene erosion, and, as the type section of the Merced sediments in middle California also indicates enormous Pleistocene degradation, a rather remarkable coincidence would also be necessary for such a reduction. Erosion comparable to that shown is present in many areas of high relief in California, but in the absence of faunal keys the Pleistocene and pre-Pleistocene degradation can not always be separated.

The stratification and lithology of the lower Pleistocene marine sediments, illustrated in Figures 1 and 2, indicate that they conceivably could have been deposited in a time interval of 80,000 years or less. On the other hand, as none of them was laid down in deep water, the rate of subsidence would necessarily have been very great to arrive at so small a figure.

The erosion of 5,000 ± feet of strata in Sierran and Glacial times, and in the initial stages of the Champlain subsidence, represents a vastly longer period. At the rate of erosion now existent in Ventura Basin, the removal of 5,000 feet of rocks would take many millions of years. There is every indication, however, that the surface of this region was considerably elevated during much of the Pleistocene. Appreciable

elevation, combined with youthful topography and soft rocks, would have been accompanied by rapid degradation.

The rate of erosion in certain basins[1] of the world has been estimated to range from 1 foot in 47,000 years, to 1 foot in 400 years. In order to take minima, we may consider the rate of erosion in a highly elevated Ventura Basin to have been, during much of Pleistocene time, twice as rapid as the highest rate of erosion reported above. If, for instance, we assume that during an oscillating rise of Ventura Basin to high elevations and a return to sea-level the erosion averaged 1 foot in 200 years, the mean surface of the land would have been lowered 3 inches in the average man's lifetime. Yet at even such a truly enormous rate of erosion, the removal of the rocks shown in Figure 2 represents a duration of 1,000,000 years. The writer considers such a duration to be almost certainly a minimum,—in fact, far too low. To this figure, and that representing the deposition of the lower Pleistocene marine sediments, we must add the time, even if short, when this part of Ventura Basin was under the sea at a late oscillation during the Champlain subsidence.

The Pleistocene erosion in Ventura Basin is comparable to that in the Sierra Nevada mountains of east-central California, where new river channels were cut to depths of 3,000 to 6,000 feet; and to the cutting of the inner gorge of the Grand Canyon of the Colorado, which is 3,000 feet deep. It is by no means exceptional for areas of youthful topography and high relief. Geologists working in regions of low relief should not, however, expect to find such amounts of erosion, for the land would there degrade at a small fraction of the rate which prevailed in more favorable localities. In fact, deep valleys in Nevada are indicated to have been aggraded several thousand feet by Pleistocene detritus.

With reference to the relative duration of the Pleistocene epoch and that of some other epochs of the Cenozoic era, it may be remembered that the Pliocene and Oligocene(?) sedimentary records in Ventura Basin are apparently complete, and the record of the Miocene possibly entire. The three epochs taken together are represented by 22,000 ± feet of strata, almost or quite conformably deposited. The Pleistocene is represented by 2,500+ feet of strata and 5,000 ± feet of subsequent erosion. The evidence of the later and maximum Cenozoic sections in southern California indicates that only pre-glacial erosion

[1]Referred to by Charles Schuchert, *op. cit.*, p. 104.

in the Pleistocene has previously been minimized, and that the Pliocene, Miocene, and Oligocene durations agree with those given in standard text-books.

The Cenozoic marine invertebrate faunas of California are of the usual stratigraphic value, but when checked against unbroken sedimentary successions are found to be peculiarly unreliable as a means of computing relative durations. Faunal aspects in California may vary only moderately through thousands of feet of strata, and then be revolutionized in a few hundred feet of conformable sediments. The more marked evolution in the shallow water life of the Cenozoic era would seem to have progressed by surges.

INDICATED DIVISIONS OF THE PLEISTOCENE EPOCH

The Pleistocene was defined by Lyell[1] as follows:

> .....I propose, in this volume, to adopt the term Pleistocene for the lower subdivision of the Post-Tertiary, retaining only sometimes in brackets the word Post-Pliocene, to remind the reader who is accustomed to that term that Pleistocene is used as its synonym.

The writer believes that sufficient evidence is available to recognize four divisions of the Pleistocene, as here outlined. These divisions are particularly well marked in California, but their epeirogenic aspects and the work of geologists in other districts indicate that they have a much wider application.

Lower Pleistocene (*Pedroian*).—The San Pedro formation (lower San Pedro *series*) of southern California embraces the lowest undisputed marine Pleistocene sediments, to which may be added the overlying Hall Canyon strata. This horizon is so far definitely known only from those deeper geosynclinal portions of California which successfully resisted the first oscillations of the Quaternary epeirogenic movement. The writer has therefore added *ian* to the typical name. The Pedroian is believed to represent the lowest division of the Pleistocene, for it is locally conformable with sediments which are transitional from the Pliocene.

Middle Pleistocene (*Sierran*).—The Sierran division occurs above marine invertebrate fauna of Pleistocene age. It was essentially an interval of elevation and erosion, interpreted by the present writer as occurring above the highest horizon of the Pedroian sediments and

[1]Charles Lyell, *Antiquity of Man*, 4th ed. (1873), p. 4.

below the horizon of the first ice sheet to invade low latitudes during the epoch.

Upper Pleistocene (*Glacial*).—The Glacial division of the Pleistocene follows the Sierran interval of erosion, and embraces glacial, interglacial, and equivalent horizons. The division is interpreted as beginning with the invasion of the first ice sheet into low latitudes in the Pleistocene, and as ending with the retreat of the last ice sheet.

Uppermost Pleistocene (*Champlain subsidence*).—The Champlain subsidence is viewed as embracing all post-Glacial time in the Pleistocene epoch, as well as that portion of the general event revealed by a partial recovery in elevation at the typical locality and elsewhere.

With reference to the relative duration of the four divisions here outlined, the writer considers that the Pedroian and the Champlain subsidence were by far the shortest. The Sierran and Glacial divisions are indicated to have had much longer durations.

Attention is called to the similarity which exists between the Quaternary epeirogenic records of eastern and western North America in all major events except the early Pleistocene marine sediments in the deepest geosynclinal portions of California. Elevation is reported from both coasts, subsequent and enormous erosion occurred in both districts, glaciation took place after the greater portion of this erosion, and subsidence is indicated in each area at approximately the same time. Minor variations doubtless occurred. The larger and grander features of the past would nevertheless appear to show, despite lagging and local variations, that the major epeirogenic movements of geologic time have been of widespread effect.

SUMMARY AND CONCLUSIONS

A critical and rapid change from Pliocene to Pleistocene marine invertebrate faunas is present in California. The lower Pleistocene faunas of the district obviously precede the great interval of elevation and erosion, and, in accordance with Lyell's definition of the Pleistocene, necessitate an inclusion of the Sierran within the epoch.

The existence of a major epeirogenic movement in the Quaternary period is evidenced by the fact that one of the largest hiatuses, if not the largest, in the known marine record of the Cenozoic era, exists between the lower and the uppermost Pleistocene. The hypothesis that this epeirogenic movement increased with oscillations to a peak and then decreased, is so far based on five kinds of evidence: (1) the first

three oscillations recorded in the lower Pleistocene marine series were visibly of ascending severity; (2) the major portion of Quaternary elevation and erosion was subsequent thereto, and of a nature indicating that one or more stronger oscillations occurred; (3) extensive glaciation took place at times when culminating oscillations might be expected; (4) submarine terraces which exist on the continental shelf suggest that oscillations may have interrupted a general subsidence; and (5) one or more late oscillations of record were of diminished effect. There was sufficient time for the supposed ponderous movements, for the 3,000 to 6,000 feet of local erosion previously reported is now 5,000 feet of erosion clearly subsequent to Pleistocene marine faunas.

In presenting in Figure 6 an ideal graph of the Quaternary epeirogenic movement in North America, the writer does not mean to suggest that the glaciation which occurred in the latter part of the Pleistocene epoch necessarily involved prodigious altitudes, although elevation is recorded by a major hiatus, and is believed to have been a contributing factor. The postulated oscillations need have occasioned only moderately increased variations in altitude in order to have profoundly affected a given balance. Coleman[1], in a recent treatise, although he does not refer specifically to epeirogeny unless a reference to isostasy be so considered, recognizes the rôle which is played in the production of ice sheets by the arrangement of land and sea, the direction of winds and ocean currents, and the relative position of mountain chains, tablelands, and plains. The present writer considers that epeirogeny is a chief cause of widespread variation in some of these factors. Schuchert[2] has called attention to the peculiar affinity which has existed in geologic time between marked disturbances of the earth's crust and glaciation. Such disturbances probably accompany epeirogenic cycles.

Some terrestrial faunas and floras of middle Pleistocene age may previously have been assigned to the Pliocene for the reason that they represent an interval of erosion, and could not be compared with the marine standard. Where these are found to have existed subsequent to the critical period in the marine succession, they should be reclassified.

The accumulation of large quantities of petroleum in southern California during the Pleistocene is not particularly surprising when

[1]A. P. Coleman, *Ice Ages Recent and Ancient* (1926), pp. 45, 52, 53, 64.

[2]Louis V. Pirsson and Charles Schuchert, *Text-Book of Geology*, Part II (1924), p. 660.

the major features are recognized. The principal deformation of the reservoir sediments in the district started early in the epoch, and the economic structure assumed much of its present inclination in middle Pleistocene time.

ALTERED PALEOZOIC VOLCANIC MATERIALS AND THEIR RECOGNITION[1]

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ABSTRACT

As altered volcanic materials are being found in the Paleozoic, there is an interest in the criteria for their recognition. The relict glass structure, the nature and habit of the crystal grains, and the physical properties present evidence that indicates the mode of origin. Bentonite is a common type of altered volcanic material and may be recognized by the volcanic structure preserved in the clay substance, and the origin is confirmed by the presence of volcanic minerals. The chemical and physical properties of bentonite are variable and many are indefinite; thus, although they may contribute to its recognition, as a rule they can not be relied upon completely. Bentonites from several of the eastern United States, Nova Scotia, Arkansas, Texas, and New Mexico are described in detail. It is concluded that many volcanic materials, even though highly altered, may be recognized by microscopic and physical studies and may contribute to the interpretation of the geologic history of a region.

Beds of volcanic materials record periods of volcanic activity and where interbedded with ordinary sediments they form key strata that are being used more and more by those engaged in stratigraphic studies. For these reasons geologists are interested in the criteria for the determination of the more profoundly altered and less easily determinable volcanic materials, such as those of Paleozoic age that have been described. Beds of bentonite are now being found in great numbers in the Tertiary of the Gulf coastal region, where they had long been unsuspected. Most of these are being recognized only as a result of detailed stratigraphic and petrographic studies, and the older volcanic beds of the Paleozoic require even more intensive study before they are detected.

CRITERIA OF RECOGNITION

Most of the known volcanic materials of the Paleozoic are highly altered, and the alteration may take several forms. The crystalline feldspathic material may become kaolinized; the glassy fragments and even parts of the crystal grains may be replaced by calcite or other carbonate; the tuff may be silicified; or the glassy portion may undergo

[1]Published by permission of the director of the United States Geological Survey. Manuscript received by the editor, November 19, 1927.

a profound alteration that consists in devitrification and the abstraction of most of the bases and part of the silica, the result being a clay-like material called bentonite.

The following definition has been proposed for bentonite[1]:

> Bentonite is a rock composed essentially of a crystalline, clay-like mineral formed by the devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash; and it often contains variable proportions of accessory crystal grains that were originally phenocrysts in the volcanic glass. * * * The characteristic clay-like mineral has a micaceous habit and facile cleavage, high birefringence, and a texture inherited from volcanic tuff or ash, and it is usually the mineral montmorillonite but less often beidellite.

Bentonite has the physical property of swelling into a gelatinous mass or disintegrating into a granular or fluffy aggregate, and it has marked powers of adsorption. No non-bentonitic clay, so far as known, shows marked properties of swelling, but some swell slightly, and many non-bentonitic clays slough down into a fluffy aggregate. Clays of the fuller's earth type show great powers of adsorption. For these reasons it seems impossible to define a bentonite by its physical properties alone.

The crystalline materials of the bentonite beds, which represent igneous-rock phenocrysts and admixed detrital materials, resist alteration and commonly retain all their original characteristics. If the original volcanic ash contained a large proportion of glass, the resulting material is largely clay and is called a bentonite, and if detrital crystalline grains are plentiful it is called a sandy or arkosic bentonite or a bentonitic arkose[2]. Tuffs that consist dominantly of crystals and crystal fragments are called crystal tuffs by Pirsson[3], and those that consist dominantly of crystalline rock fragments are called lithic tuffs.

Several lines of evidence may contribute to the determination of the volcanic origin of tuffs and altered tuffs. Evidence is afforded by the presence of minerals of volcanic origin, by lithic rock fragments with typical volcanic-rock structure, and by the presence of volcanic glass or of altered glass that retains characteristic structure inherited from volcanic glass. Some of the physical properties, such as reaction to water, the texture, and the optical properties, and the chemical composition may help in the recognition of bentonite.

[1]Clarence S. Ross and Earl V. Shannon, "The Minerals of Bentonite and Related Clays and their Physical Properties," *Am. Ceramic Soc. Jour.*, Vol. 9 (1926), p. 79.

[2]Clarence S. Ross and Earl V. Shannon, *op. cit.*, p. 79.

[3]Louis V. Pirsson, "The Microscopical Character of Volcanic Tuffs: a Study for Students." *Am. Jour. Sci.*, 4th ser., Vol. 40 (1915), pp. 191-211.

The presence of euhedral crystals of biotite, feldspar, pyroxenes, or hornblende is evidence of volcanic origin, for rarely if ever do these crystals have euhedral form in materials derived from plutonic rocks. According to the rule that some minerals or mineral habits are characteristic of certain types of rock, sanidine and zoned plagioclase indicate volcanic origin. It is also evident that pure volcanic materials will as a rule contain a simpler suite of minerals than would be found in most detrital materials. Pre-Cambrian rocks are the dominant source of Paleozoic detrital sediments in the eastern United States, and these furnish plagioclase, microcline, hornblende, muscovite, biotite, and generally metamorphic minerals like garnet, cyanite, and andalusite. The association of sodic and calcic plagioclase and the presence of microcline (which is not a mineral of volcanic rocks), muscovite, and garnet would tend to indicate detrital rather than volcanic origin.

Most of the ordinary clays contain many grains of detrital quartz, but such material is never a pure bentonite formed directly from volcanic ash, although re-worked and re-deposited volcanic ash may contain detrital quartz. A few sedimentary clays and shales are practically pure clay material, and most of these show sedimentary lamination, but very rarely a sedimentary clay is so homogeneous that there is no internal structure except a perfect extinction between crossed nicols parallel to the bedding. True bentonites may contain rather coarse grains of fragmental quartz, feldspar, and other minerals, but, unlike most shales, they do not contain much detrital quartz. There is therefore seldom or never a similarity in composition between sedimentary shales and pure bentonites. It is, however, often difficult or impossible to distinguish re-worked and re-deposited tuffs and bentonites from detrital sedimentary clays.

Lithic tuffs are formed from quickly cooled volcanic material, and this mode of origin gives them a fine-grained structure and commonly a crystal fabric that can not be mistaken. Vitric tuffs[1] composed of glass fragments definitely establish volcanic origin, but they have not been observed in Paleozoic tuffs. All the Paleozoic tuffs that have been recognized were originally composed dominantly of glass fragments, and the structure assumed by such fragments becomes an important factor in their recognition. The varieties of glass relict structures have been well described by Pirsson[2], and they are so characteristic where well preserved that they constitute the most conclusive evidence of volcanic

[1]Louis V. Pirsson, *op. cit.*

[2]*Idem.*

origin. Glassy fragments assume three principal habits. One type is composed of fragments of glass that once inclosed rounded bubbles and consists of curved or lune-shaped fragments of the bubble walls, of Y-shaped fragments that were formed where three bubbles were in close proximity, and of double-concave plates that formed the wall between two adjoining bubbles. A second type is made up of nearly flat glass plates that were formed by the fragmentation of the walls that inclosed large flattened lens-shaped vesicular cavities. The third type has a fibrous structure and represents pumice fragments with minute elongated vesicular cavities and the inclosing glass walls. All these structural forms may be distorted, but they are rarely completely obliterated, and even metamorphosed bentonites have a heterogeneity that can not be ascribed to sedimentary processes but is due to modified glass relict structure.

The alteration of glassy tuff involves a profound chemical change that may modify the volume of the final product, and consolidation of originally porous material will tend to distort the individual fragments. Beds in the older geologic formations and especially those in regions of metamorphism may be further distorted and recrystallized and their structure modified. All these destructive processes tend to obliterate the structure characteristic of volcanic glass, but fortunately a surprisingly large proportion of altered volcanic tuffs retain clear evidence of their origin. Many bentonites that contain nothing but clay material retain structure that was developed in glassy tuff fragments and that is just as well preserved and just as diagnostic as that of the unaltered glassy material. Several factors seem to contribute to the preservation of structure. Silica and bases are abstracted during the process of alteration, but water is added, and the total volume seems to remain about the same. Porosity is partly eliminated by compacting the deposit, and the tuff fragments become slightly warped, but this does not destroy their character. The distortion is greater in the vertical than in the horizontal direction, and therefore thin sections cut parallel to the bedding are commonly better than those cut perpendicular to it. When the ash deposits fall on land and are re-worked and re-deposited the characteristic structure may be completely destroyed, but the nature of the clay mineral and the presence of igneous-rock phenocrysts may suggest a volcanic origin even though conclusive evidence may be lacking.

The physical properties of bentonites have been strongly emphasized by some investigators. Swelling in water has been said to be a

property of bentonites[1], but most bentonites do not swell greatly when placed in water or form permanent suspensions, and many bentonites do not even make the water cloudy. The physical structure, the essential bases, and the adsorbed salts are probably all factors in controlling the swelling of bentonites and their ability to form permanent suspensions, and appropriate chemical treatment will render all bentonites capable of forming permanent suspensions. Many bentonites that have not become indurated by the infiltration of quartz or calcite or that have not been metamorphosed and dehydrated crumble or slack down into a granular or fluffly aggregate when placed in water if they are first air dried. There is no swelling or breaking down in the presence of ground water if the deposit is under even slight load, as where it is overlain by other beds a few tens of feet in thickness. For this reason the structure of bentonite is destroyed only at the surface, and so bentonites very commonly retain ample evidence of their volcanic origin.

Bentonites, especially dried specimens, commonly have a waxy translucence that is one of their most distinguishing characteristics. Practically all ordinary shales, clays, and slates are highly opaque, but thin plates of most bentonites transmit light. This can be most readily observed when small fragments are examined in good light under a binocular. The presence of this property can be accepted as fairly good evidence of bentonite, but its absence does not show that the material is not bentonite, for some undoubted bentonites do not show it.

The clay minerals that have replaced glass in bentonites are micaceous in habit, having a very perfect basal cleavage and a birefringence about equal to that of mica. In thin sections of some specimens this cleavage can be easily observed, but in others the fineness of grain makes it difficult to see. The micaceous plates ordinarily stand perpendicular to the original margin of the glassy fragment, but in some specimens there is a core where the elongation of the mineral plates is parallel to the elongation of the fragment.

Many bentonites do not entirely disintegrate into individual crystal fragments when placed in water, but those that form permanent suspensions break down almost completely. After disintegration those of the first type show small aggregates of crystal groups under the microscope, and those of the second type are composed dominantly of minute single crystal plates. The groups commonly show areas that exhibit the char-

[1]Frank C. Schrader, Ralph W. Stone, and Samuel Sanford, "Useful Minerals of the United States." *U. S. Geol. Survey Bull. 624* (1917), p. 356.

acteristic birefringence, but the minute single plates tend to lie in a horizontal position in which the birefringence is so low that it is difficult to observe. Some bentonites contain a large proportion of clay material in which the plates lie approximately parallel to the bedding, and these show more birefringence in sections cut perpendicular to the bedding than in those cut parallel to it. This characteristic is produced by the compacting of the bed and may in some deposits be accompanied by metamorphism.

The dominant and typical clay mineral of bentonite is montmorillonite of the composition $MgO \cdot Al_2O_3 \cdot 5SiO_2 + nH_2O$ but with part of the MgO replaced by CaO, FeO, etc., and a very small part of the Al_2O_3 replaced by Fe_2O_3. Bentonites, however, are derived from latitic and rhyolitic rocks low in Fe_2O_3, and the montmorillonite in bentonites seldom contains large proportions of Fe_2O_3. Montmorillonite normally has about the indices of refraction α=about 1.49, β=about 1.51, but an excess of alkalies or a loss of water will raise the indices. The birefringence is about 0.03, and extinction is always parallel to the perfect cleavage.

The bentonites from Highbridge, Kentucky, and from Lexington and Catawba, Virginia, and a bentonite from Suifu, China, are potash-bearing. Doctor Kerr, of Columbia University, who is making a detailed X-ray study of the clay minerals, finds that these potash-bearing bentonites give a distinct diffraction pattern which seems to indicate that an unnamed clay mineral characterizes a few bentonites.[1]

The dominant clay mineral in detrital sedimentary materials and very rarely in bentonites appears to be beidellite ($Al_2O_3 \cdot 3SiO_2 \cdot nH_2O$). There is complete isomorphism between beidellite and nontronite ($Fe_2O_3 \cdot 3SiO_2 \cdot nH_2O$)[2], and a large number of the ordinary sedimentary clays contain considerable proportions of the iron end member of the beidellite-nontronite series. They are therefore quite likely to show a slight brownish color in thin section, and the birefringence is normally a little higher than it is in montmorillonite. The clay aggregates of beidellite may be more smearlike and less sharply bounded than the bentonitic clay aggregates that are secondary to glass. Some sedimentary shales have clay particles that resemble sericite in small distinct plates, but these do not form characteristic aggregates like those in bentonites, and the individual plates nearly all show orientation parallel to the bedding.

[1]Personal communication.

[2]Esper S. Larsen, and George Steiger, "Dehydration and Optical Studies of Alunogen, Nontronite, and Griffithite," *Am. Jour. Sci.* 5th series, Vol. 25 (1928), pp. 14, 15.

Montmorillonite, beidellite, and probably a third unnamed clay mineral have been identified in bentonite, but montmorillonite is the most widespread bentonitic clay mineral. Montmorillonite is also known but is not common in non-bentonitic clays. Therefore analysis of the pure clay mineral is significant though not conclusive in determining bentonites, but analyses of gross samples that may contain quartz, feldspar, and other crystal grains, secondary quartz, calcite, ankerite, and adsorbed bases have little significance.

Most of the water in bentonites is probably adsorbed, and other elements and especially alkalies may be adsorbed in its place. It is a well-known fact that potash is adsorbed in greater proportion than soda.[1] Therefore the alkali content does not serve to identify a bentonite, even when it is known that only clay mineral is present, and it is evident that in a gross sample that contains appreciable proportions of feldspar the alkali content will be largely determined by the nature of the included feldspar grains.

To recapitulate, the features that are useful in the determination of bentonites, listed in the order of their apparent reliability, are as follows:

Presence of glass relict structure.
Presence of minerals and crystal forms characteristic of volcanic rocks (euhedral, zoned, etc.).
Absence of minerals that do not have a volcanic origin (microcline, garnet, muscovite, calcic and soda plagioclase) in the same specimen.
Waxy luster.
Reaction to water.
Optical properties.
Chemical properties.

LOCALITIES OF ALTERED PALEOZOIC TUFFS

Volcanic tuffs of Paleozoic age occurring east of Mississippi River were first reported by Nelson[2] from Tennessee, Kentucky, and Alabama, and the Alabama locality was later described by Butts.[3] The knowledge that tuffs might be expected in the eastern United States led to their discovery three years later by Bonine[4] in Pennsylvania,

[1]Eugene C. Sullivan, "The Interaction between Minerals and Water Solutions," *U. S. Geol. Survey Bull. 312* (1907), p. 23.

[2]Wilbur A. Nelson, "Volcanic Ash Bed in the Ordovician of Tennessee, Kentucky, and Alabama," *Geol. Soc. America Bull.*, Vol. 33 (1922), pp. 605-16.

[3]Charles Butts and others, "The Geology of Alabama," *Alabama Geol. Survey Special Rept. 14* (1926), pp. 113-14, 131.

[4]C. A. Bonine, "Researches in Sedimentation in 1925 and 1926." *Committee on Sedimentation Rept.*, pp. 4-5, 1926.

and Walter H. Bucher reported volcanic ash in Ohio in a personal communication to Nelson.[1] A tuff bed was found in Virginia by Nelson[2] in 1925, and has been discussed by Giles.[3] In 1926 another Virginia locality was discovered by Butts.[4] During the summer of 1927 deposits of bentonite were found in the vicinity of Roanoke by Nelson[5] and in several places by Herbert P. Woodward.[6]

Altered volcanic tuffs and ash have been identified from the Mississippian of Arkansas[7] and Oklahoma[8]; in New Brunswick[9] and Nova Scotia[10]; and from the Permian of Texas and New Mexico.[11]

The most widespread bentonites of the eastern United States occur in Tennessee, Kentucky, and Alabama. They have been recognized at five different horizons in Tennessee. A bed near the top of the Stones River limestone is well shown about a mile south of Lone Mountain, Claiborne County, Tennessee.[12] This is considerably lower in the section than the two more widespread beds previously found—one at the top of the Lowville limestone and the other at the base of the Trenton. At one time Nelson considered the Lowville bed to be the more widespread, but he now recognizes that the one at the base of the Trenton may have the wider distribution of the two.[13] There are two or three other bentonite beds near the contact of the Lowville and the Trenton.

[1]Wilbur A. Nelson, *op cit.*, p. 606.

[2]Wilbur A. Nelson, "Volcanic Ash Deposit in the Ordovician of Virginia," *Geol. Soc. America Bull.*, Vol. 37 (1926), pp. 149-50.

[3]Albert W. Giles, "The Origin and Occurrence in Rockbridge County, Va., of so-called 'Bentonite.'" *Jour. Geol.*, Vol. 35 (1927), No. 6, pp. 527-41.

[4]Personal communication.

[5]Personal communication.

[6]Personal communication to Nelson.

[7]H. D. Miser, "Mississippian Tuff in the Ouachita Mountain Region." *Geol. Soc. America Bull.*, Vol. 31 (1920), pp. 125-26.

[8]C. W. Honess, "The Stanley Shale." *Am. Jour. Sci.*, 5th ser., Vol. 1 (1921), pp. 63-80; *Oklahoma Geol. Survey Bull. 32* (1923), pp. 179-202.

[9]W. J. Wright, "Geology of the Moncton Map Area." *Canada Geol. Survey Mem. 129* (1922), pp. 13-14.

[10]Material collected by Sidney Powers and examined by C. S. Ross.

[11]Material collected by W. B. Lang and examined by C. S. Ross.

[12]Wilbur A. Nelson, "Two new Volcanic Horizons in the Stones River Group of the Ordovician of Tennessee." *Geol. Soc. America Bull.*, Vol. 36 (1925), p. 159; also unpublished manuscript.

[13]Personal communication.

The material submitted by Nelson from the locality 1 mile south of Lone Mountain is a typical bentonite. The color is nearly white, with a bluish-green tint. The hand specimen shows large numbers of euhedral biotite crystals that are nearly a millimeter in diameter. The microscope shows biotite and orthoclase phenocrysts that are inclosed in a bentonite groundmass composed of fragments that retain the fluidal structure characteristic of many glassy rhyolites. The mineral composition as determined by the Rosiwal method is as follows:

MINERAL COMPOSITION OF BENTONITE FROM LONE MOUNTAIN, TENNESSEE

Bentonitic clay mineral	77
Angular quartz	18
Orthoclase	4
Biotite	2

Most of the minerals are sharply angular, but part of the biotite is euhedral. The individual tuff fragments reach a maximum length of 0.7 millimeter and have an average diameter of 0.4 millimeter.

Material collected by Nelson from a bentonite bed at Highbridge, Kentucky, is typical of the bentonite layers that occur near the top of the Lowville limestone of the Ordovician in Tennessee and Kentucky, and is also typical of a similar layer of bentonite that occurs just above the Lowville formation in the base of the Trenton. The color is light green. Parts of the bed are nearly pure clay material with few phenocrysts, and other parts are rich in phenocrysts that average about 0.5 millimeter in diameter. A typical specimen has the following mineral composition:

MINERAL COMPOSITION OF BENTONITE FROM HIGHBRIDGE, KENTUCKY

Bentonitic clay mineral	79
Orthoclase	16
Quartz	3
Biotite	2

Most of the minerals are sharply angular, but much of the biotite is euhedral. Structure typical of volcanic glass is not retained by the bentonitic clay, but the nature of the phenocrysts gives clear evidence of its origin. Orthoclase forms 76 per cent of the phenocrysts; and microcline, plagioclase, muscovite, hornblende, and rounded quartz grains are absent. Such mineral relations are found only in a volcanic material.

Butts has described two beds of bentonite in the Chickamauga limestone of Alabama.[1]

> The oldest bed is in the limestone of early Black River (Lowville) age and is exposed on the west slope of Red Mountain, 2 miles northwest of Attalla. * * * The other bed is the base of the limestone of Trenton age on Red Mountain, Birmingham, and in the bottom of the Woodward shaft in Shades Valley about 3 miles southeast of Bessemer.

The material of Lowville age near Attalla is an arkosic bentonite. The color is nearly white with a slight yellow-green tint, and the individual clay granules are very pale green and have a waxy translucence. The mineral composition is 70 per cent bentonitic clay and 30 per cent orthoclase. Quartz, biotite, apatite, and zircon form less than 1 per cent of the rock. A microscopic study shows that the structure of glassy pumice is very perfectly preserved in the bentonitic clay material. A large proportion of the orthoclase is euhedral. It is evident that the orthoclase originally inclosed numerous blebs of glass—a common characteristic of feldspar in volcanic rocks—and this glass is now altered to bentonite.

The material from the beds of Trenton age on Red Mountain, Birmingham, is a dark-gray bentonite with waxy translucence. Hand specimens show large, conspicuously black euhedral crystals of biotite. Fibrous relict structures of glass pumice are well preserved. The bentonite has the following mineral composition:

MINERAL COMPOSITION OF BENTONITE FROM BIRMINGHAM, ALABAMA

Bentonitic clay mineral	80
Orthoclase	13
Biotite	4
Quartz	3
Zircon	Traces

A volcanic material occurs at the roadside on the State highway from Lexington to Natural Bridge, about 5 miles south of Lexington, Rockbridge County, Virginia. The horizon is in the Ordovician and, according to Ulrich, near the base of the Trenton. The main bed is about 8 feet thick, and a second bed about 2 feet thick lies about 75 feet south of it. The material collected by the writer is a yellow-gray, fine-grained, slightly metamorphosed shale, and much of it shows the waxy translucence that is typical of many bentonites. Metamorphism has produced a slaty cleavage, but the material is not highly indurated.

[1] Charles Butts, *op. cit.*

It does not readily disintegrate in water, and the pressure has caused partial dehydration of the clay material. It resembles slaty shale superficially, but the waxy appearance suggests a difference from ordinary shales, and its volcanic origin is confirmed by microscopic studies.

Most of the thin sections of material from the vicinity of Lexington, Virginia, are identical in microscopic texture with those from Highbridge, Kentucky, and do not show volcanic-glass structure, but some layers retain the structure excellently, as is shown in Figures 1 and 2. Those in Figure 1 are the Y-shaped and lune-shaped forms that have been so well described by Pirsson. Those in Figure 2 are curved plates that originally formed walls around nearly spherical, vesicular cavities, and other thin sections show ellipses that represent devitrified bubble walls, like those that may be seen in many ash deposits. The original hollow centers have been filled by clay material that has been re-deposited from solutions. All these forms are typical and easily recognized phases of volcanic-glass structure.

The material in the volcanic bed near Lexington varies somewhat in texture and mineral composition. That at one horizon contains phenocrysts that are made up of about 70 per cent orthoclase and about 22 per cent quartz, and in that at another horizon orthoclase forms about 96 per cent of the phenocrysts. Biotite is rare in some specimens, but it exceeds orthoclase in others. Part of the biotite is euhedral. A few quartz grains are present, and much secondary quartz forms small veinlets that cut across the bedding planes. Some of the specimens contain much calcite that has replaced the clay material. No plagioclase was recognized, and no microcline, muscovite, or hornblende is present. It is evident that detrital material from pre-Cambrian rocks would contain muscovite, one of the most resistant of minerals, and various types of feldspar with much microcline. Instead, there are only orthoclase, quartz, biotite, and a little zircon—a simple suite of minerals that is likely to be derived only from uncontaminated volcanic materials. Moreover, part of the biotite and orthoclase is euhedral.

Material of the same type, which probably represents altered bentonites, has been observed by Nelson at Honaker, Russell County, Virginia.

A bed of volcanic material in the base of the Trenton was discovered by Charles Butts,[1] of the United States Geological Survey, about 10 miles northwest of Abingdon, Russell County, Virginia, on the

[1]Personal communication.

FIG. 1

FIG. 2

FIGS. 1 and 2.—Bentonite from 5 miles south of Lexington, Rockbridge County, Virginia. The black areas are crystal grains and all the gray groundmass is bentonite. FIG. 1.—The curved figures were originally glass bubble walls whose characteristic structure has been retained in bentonitic clay. An exceptionally perfect Y-shaped fragment at the lower border shows part of an elliptical bubble (compare with Fig. 7). Enlarged 75 times. FIG. 2.—The remains of platy volcanic glass structures. Enlarged 75 times.

Abingdon-Hansonville road, in the summer of 1926, and has been visited by the writer. It is a clay bed 14 inches thick that occurs in a bed of limestone, and another thin bed is about 3 feet lower in the section. The color is yellowish gray, and a waxy translucence is present but is not conspicuous. Biotite is plentiful, but the slickensiding along cleavage surfaces tends to obscure its presence. Superficially it resembles a shale, but the igneous-rock phenocrysts and its presence in a limestone bed call attention to a marked difference between it and an ordinary shale. A microscopic examination shows the presence of phenocrysts of biotite, feldspar, and quartz. Most of these are sharply angular, but a few crystals of biotite and feldspar are euhedral (Fig. 3). The coarse crystals are evenly distributed in the clay and are not concentrated in bedding planes, as they would be in sedimentary rock. This material is obviously bentonite. The massive limestone above and below the bentonite forms highly competent beds that have resisted distortion. For this reason movements have been localized in the yielding bentonite bed, which is cut by numerous sinuous slickensided shear zones. In these the characteristic clay mineral and biotite of the bentonite have been converted into an almost colorless chlorite. An irregular band of this chlorite is shown in Figure 4. Some of the specimens contain large proportions of calcite. The clay material of this arkosic bentonite does not retain well-preserved volcanic-glass structure, but the phenocrysts are typical of volcanic materials. One sample from the Hansonville locality has the following mineral composition:

MINERAL COMPOSITION OF ARKOSIC BENTONITE FROM HANSONVILLE, VIRGINIA

Bentonitic clay mineral	71
Orthoclase	16
Biotite	11
Quartz	2

Albite forms less than 1 per cent of the phenocrysts.

During the summer of 1927 Butts found two other bentonite localities.[1] The following section is shown about 2 miles south of Blackford, Virginia, in the northwest corner of the Abingdon quadrangle:

[1]Personal communication.

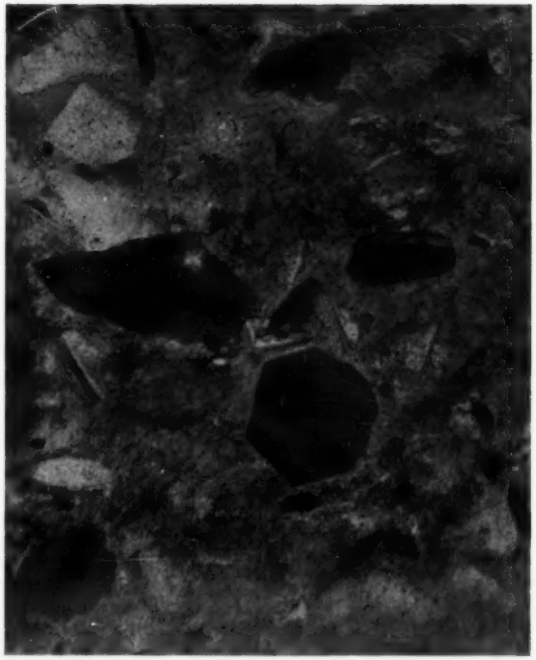

FIG. 3

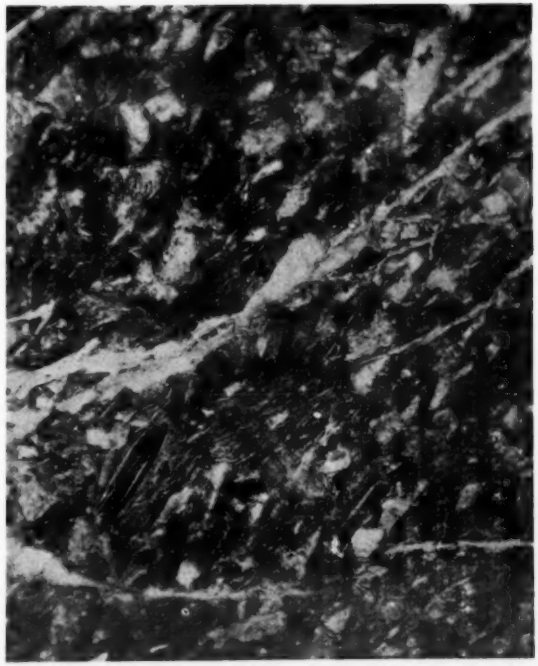

FIG. 4

FIGS. 3 and 4.—Arkosic bentonite with about 30 per cent of crystal grains from Abingdon-Hansonville road 10 miles northwest of Abingdon, Virginia. FIG. 3.—The black crystals are biotite. Near the lower center is an euhedral biotite crystal. Very light areas are orthoclase with an euhedral orthoclase crystal shown in the upper left corner. Enlarged 50 times. FIG. 4.—Black areas are biotite crystals cut perpendicular to the cleavage, and white areas are orthoclase and quartz. The white veins are shear zones where clay material and biotite have been converted into colorless chlorite. Enlarged 50 times.

GEOLOGIC SECTION 2 MILES SOUTH OF BLACKFORD, VIRGINIA

	Feet
Red limestone	1
Argillaceous limestone	40
Bentonite	5
Argillaceous limestone	40
Bentonite with thin lenses of Trenton limestone	8
Gray shale	7
Fossiliferous limestone	20+

The material south of Blackford is similar to that near Hansonville and according to Butts is in the base of the Trenton.

Butts also found bentonite at the same horizon 2½ miles south-southeast of Bland, Virginia, on the north slope of Walker Mountain.

Another Virginia locality where volcanic materials are present was discovered about 2 miles east of Catawba, Roanoke County, by Wilbur A. Nelson[1] in the spring of 1927, and since then this same horizon has been identified by Herbert P. Woodward[2] at two other localities in the vicinity of Roanoke. It is in the base of the Trenton. Several types of material are present, as is shown by the following geologic section:

GEOLOGIC SECTION AT BENTONITE LOCALITY NEAR CATAWBA, VIRGINIA[3]

	Inches
Yellow sandy shale	7
Coarse yellow sandy bentonite	6¾
Red shale	1¼
Yellow micaceous bentonite	5½
Red and yellow bentonite	2½
Dark-red sandy shale	5

A sample from the upper part of the bed that is composed of sandy bentonite is nearly opaque, and the red shale is almost completely opaque, like nearly all ordinary shales, but the lower part has a very decided waxy translucence. The upper part is a light yellowish-gray, and the lower part is light greenish-gray and dull reddish-purple. Biotite is very plentiful in all the specimens. The opaque red shale parting between two bentonite layers is not bentonitic, and this probably indicates that at least two distinct ash showers were represented. The Catawba bed contains volcanic-rock phenocrysts of the same character

[1]Personal communication.

[2]Personal communication to Nelson.

[3]Section by Nelson, personal communication.

as those in the bed near Hansonville. The relative portions of minerals in the upper layer are as follows:

MINERAL COMPOSITION OF BENTONITE FROM CATAWBA, VIRGINIA

Bentonitic clay mineral	75
Biotite	12
Quartz	7
Orthoclase	5
Zircon	1

The lower layer contains about 3 per cent of orthoclase and 9 per cent of biotite.

At the Lexington deposit the glassy material had the form of curved plates that formed the walls between bubbles and of Y-shaped fragments that represent the broken wall where three bubbles adjoined. At Catawba the glass was all in the form of a fine-grained pumice with minute elongated vesicular cavities. These structural features are well preserved and are pictured in Figures 5 and 6. There has been no shearing and no development of chlorite, as at Hansonville. The material swells in water and has all the physical properties of western bentonites that are being used for commercial purposes.

The bentonite from Bellefonte, Center County, Pennsylvania, which was discovered by Bonine[1] and examined by Butts,[2] has been known for some years. A sample collected by Butts from the Bellefonte bentonite bed is bluish-gray with a waxy translucence. Phenocrysts of orthoclase and biotite are present in small numbers and euhedral zircon is very plentiful. The ash was evidently very fine-grained, and fragments averaged about 0.02 millimeter in diameter, but it retains the structure of a pumice with elongated bubble walls. This occurrence has been studied by Bonine, Honess, and others of Pennsylvania State College, who have positively identified the volcanic structure.[3]

The volcanic materials of Virginia, with the exception of that from the Catawba locality, are superficially the least like bentonites and the most difficult to recognize of all the Paleozoic deposits studied. Several of the deposits have been studied by the writer in the field; about 75 thin sections have been made and examined, the crystal grains

[1] C. A. Bonine, *op. cit.*

[2] Personal communication.

[3] C. A. Bonine, *op. cit.*

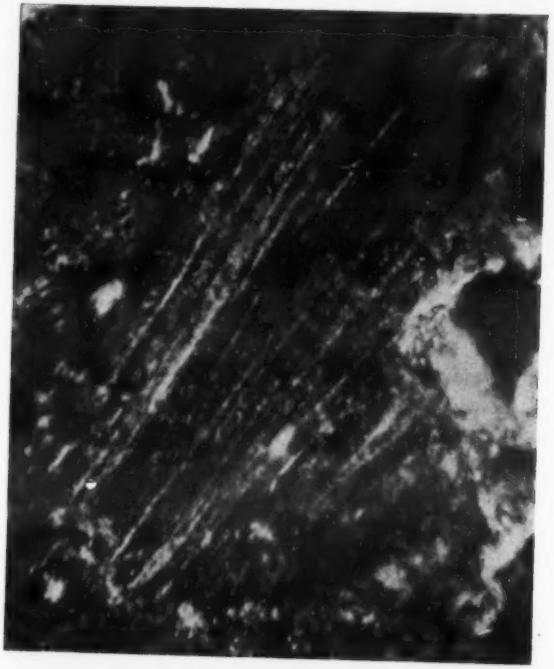

FIG. 5

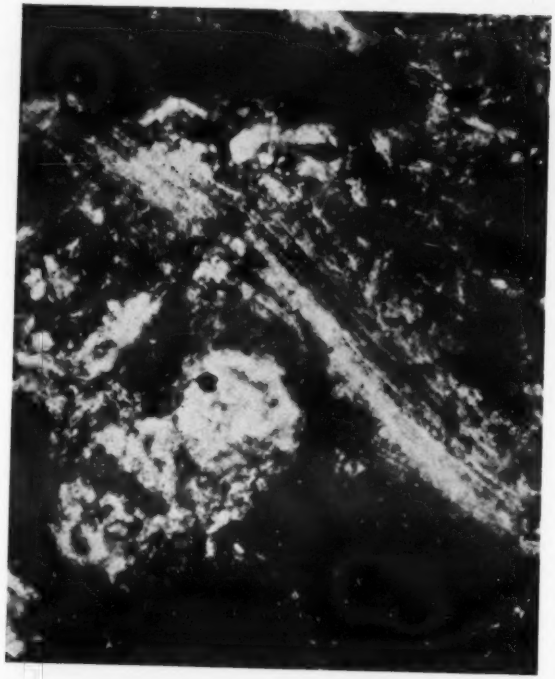

FIG. 6

FIGS. 5 and 6.—Bentonite from 2 miles west of Catawba, Virginia. The fibrous structure characteristic of volcanic glass composed of fine-grained pumice preserved in bentonitic clay. Enlarged 820 times

have been isolated and their identity determined by immersion methods, and the proportions of the different minerals have been ascertained.

The Paleozoic volcanic materials that have been identified appear to have been formed from rhyolitic or latitic ash beds, and material of this type shows a strong tendency to undergo alteration to bentonite soon after deposition. At still later periods there may be a partial replacement by calcite and quartz, and in regions where orogenic processes have been active there may be various degrees of metamorphism. Some of the Paleozoic volcanic deposits—such as those in the Permian of New Mexico and some of those in Kentucky, Tennessee, Alabama, and Virginia—have the same physical characteristics as the Cretaceous and Tertiary bentonites of the western United States, but many of them in the eastern states are more compact, harder, and dryer than the younger bentonites. Thus some of them resemble a fine-grained, compact, slightly metamorphosed shale. It must be remembered that bentonite is only clay or shale that has had a particular origin, and it may undergo the same type of metamorphism as any other clay or shale and result in phyllite or slate as an end product.

The Ordovician volcanic deposits that have altered to clay material are the oldest of this type that have been recognized, and the evidence of their origin is the least obvious. The exceptional character of the beds in Tennessee, Alabama, and Kentucky has been known for some years, but not till 1921 were they generally recognized as volcanic deposits, with structure and physical properties similar to those in many of the bentonites of the western states. The material at Bellefonte, Pennsylvania, was next recognized and has been thoroughly studied and its volcanic nature established. The deposit near Lexington, Virginia, was next discovered. It is the most highly metamorphosed of the beds, and the difficulties of its study have delayed its recognition as volcanic material. Some parts of the bed are fine-grained and lack volcanic-ash structure, but others retain so perfectly the structure of volcanic glass that petrographic studies clearly establish volcanic origin. The studies of Kerr[1] show that the X-ray diffraction pattern of the Lexington material is identical with that given by undoubted bentonite from Catawba and Highbridge and indicate the mineralogical identity of the clay mineral in widely separated deposits of Ordovician bentonite. The occurrence of volcanic materials in the Ordovician of Virginia has been further confirmed by the discovery of such materials in southwestern Virginia near Hanson-

[1]Paul F. Kerr, personal communication.

ville, Bland, and Blatchford, and at several localities in the region around Roanoke. The Catawba deposit has the physical properties of a bentonite, and the volcanic-glass structure and the phenocrysts of a volcanic tuff leave no doubt of its origin.

The presence of Ordovician rhyolitic flows in Virginia was long ago recognized by Watson and Powell[1] in the Quantico and Arvonia slate belts and by Tabor,[2] who described a bed of tuffaceous material on the James River a mile west of Bremo Bridge. More recently Stose and Jonas[3] have described undoubted volcanic material in the Ordovician near Johnstown, Pennsylvania.

Thus Ordovician volcanic materials have been found by different geologists at many places in six of the eastern United States and have been examined by petrologists and their volcanic nature confirmed. When all the evidence is considered there can be no doubt that great volcanic eruptions occurred in Ordovician time, and deposits hundreds of miles apart show that thousands of square miles were at this time covered with ash.

Tuff beds have been reported by Wright[4] from the "lower Carboniferous," and bentonitic volcanic ash has been identified by the writer in material collected by Sidney Powers at the Malagash salt deposit of Nova Scotia. This altered volcanic ash is now in the form of a coarse-grained gritty clay of light gray color. Microscopic studies show coarse-grained volcanic-glass structure, and the fragments average about 0.2 millimeter in diameter. The relations of the ash bed to the salt are not fully known, but thin sections show veinlets of salt cutting the bentonite. The tuff structure and the veinlets of salt that cut it are shown in Figure 7.

The volcanic ash in the Mississippian of the Ouachita region has been described by Miser, who says:[5]

> Tuff of Carboniferous age occurs near the base of the Stanley shale, in the Ouachita Mountain region in Polk County, Arkansas, and McCurtain

[1]Thomas L. Watson and S. L. Powell, "Discovery of Fossils in the Quantico Slate Belt, and the Association of Volcano-Sedimentary Beds with Slates of the Virginia Crystalline Region (abstract)." *Geol. Soc. America Bull.*, Vol. 21 (1910), p. 782; *Am. Jour. Sci.*, 4th ser., Vol. 31 (1911), pp. 33-44.

[2]Stephen Tabor, "Geology of the Gold Belt in the James River Basin." *Virginia Geo Survey Bull. 7* (1913), p. 43.

[3]George W. Stose and Anna I. Jonas, "Ordovician Shale and Lava in Southeastern Pennsylvania." *Geol. Soc. America Bull.*, Vol. 38 (1927), pp. 529-34.

[4]W. J. Wright, *op. cit.*

[5]H. D. Miser, *op. cit.*

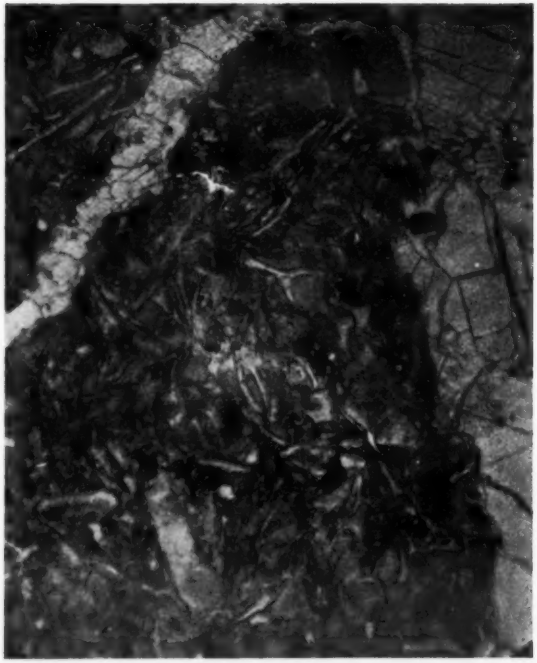

FIG. 7.—Bentonite from Malagash, Nova Scotia, salt deposit. The light-colored veins are salt. The darker areas contain platy and Y-shaped structures of volcanic ash. A Y-shaped ash fragment is shown just above the center of the figure (compare with Fig. 1). Enlarged 50 times.

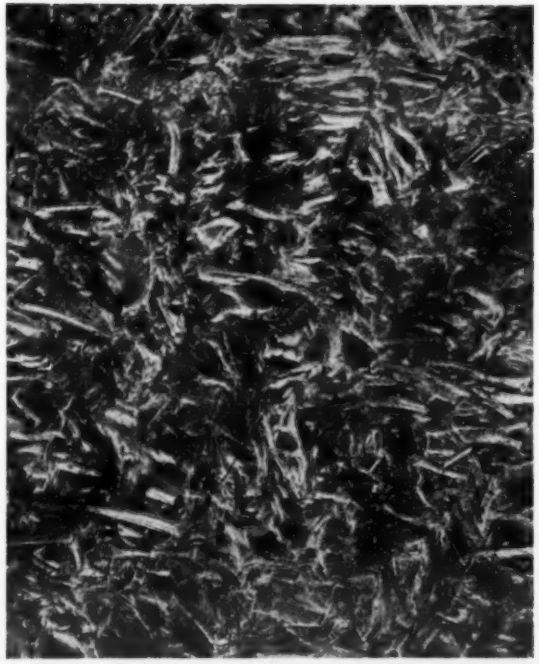

FIG. 8.—A very pure bentonite from Eddy County, New Mexico. Fine-grained, platy and slightly fibrous glass fragments are preserved in the bentonite. Enlarged 50 times.

County, Oklahoma. There are three and possibly four or five beds in it, ranging in thickness from 6 to 85 feet. All of them are very similar in lithologic character. The lowest bed is the thickest and most widely distributed. * * * The tuffs are compact, massive, and tough; are generally homogeneous, except for the presence of numerous chlorite "pellets" that lie parallel to the bedding; and in color are dark gray with a greenish tinge. Feldspar, which occurs in grains 7 millimeters or less in diameter, is generally more abundant than other minerals, which include muscovite, magnetite, pyrite, zircon, apatite, chlorite, calcite, and kaolin. Much of the tuff, however, consists of devitrified and silicified volcanic glass, of which a large part is ordinary volcanic ash and represents fragments of the walls of bubbles, though some of the larger fragments of glass are fluidal. The original rock from which the tuff was derived was probably near a rhyolitic or quartz latite.

Honess also describes these tuffs from the Ouachita Mountain region of Oklahoma[1] and says:

In general it may be said of the tuffs occurring near the base of the Stanley shale that practically all of this material when examined in plain polarized light microscopically may be seen plainly to be made up wholly or partially of angular fragments which are bounded by broadly curved, concave or convex lines meeting in sharp points, characteristic of volcanic-ash fragments known as "bogen structures." The majority of the fragments have become vitrified and between crossed nicols lose their identity in an aggregate of quartz, feldspar, sericite, and other minerals which mask the bogen structure.

W. B. Lang,[2] of the United States Geological Survey, has reported bentonite in the Permian of Crane, Upton, and Ector counties, Texas, and Eddy County, New Mexico, but has not yet published descriptions of the material. The specimens range from very light gray to dark gray with a greenish or greenish-blue tinge, and some are mottled with brighter blue-green. All show a waxy translucence. Phenocrysts are sparse, but a few phenocrysts of othoclase can be seen in the hand specimen. A microscopic study shows many small fragments of orthoclase and biotite and very perfectly preserved volcanic-ash structure. Most of the fragments are platy, but some of the fibrous-pumice type are present. These are shown in Figure 8.

CONCLUSIONS

The Paleozoic volcanic materials have had a longer history and have been subjected to a greater variety of geologic processes than the younger beds of the western United States. For these reasons

[1]C. W. Honess, "Geology of the Southern Ouachita Mountains of Oklahoma." *Oklahoma Geol. Survey Bull. 32* (1922), pp. 179-88.

[2]Personal communication.

part of the Paleozoic materials, such as the more metamorphosed beds of Virginia, lack some of the physical properties that are generally regarded as characteristic of bentonite. Some of the bentonitic tuff lacks the power of swelling or disintegrating in water; it has been partly dehydrated by deep burial and metamorphism; it is harsh to the touch and has a shale-like or even a slaty appearance. These beds, however, have a common origin with more typical bentonite. They were deposited as tuffaceous volcanic glass, and they underwent an alteration that converted the glass into a bentonitic clay. In some beds the processes of alteration stopped with the development of clay material, but in others they were continued by induration, replacement, and metamorphism. The identical mode of origin justifies an emphasis of the bentonitic character of such deposits, especially where mode of origin and not commercial value is being considered. The physical properties of bentonite give it commercial value, and those interested in its commercial use may wish to avoid the term bentonite for the metamorphosed materials. For this reason the most altered beds described in this paper may be called meta-bentonites, and still more highly metamorphosed materials of this type would be bentonitic slates and phyllites.

Highly metamorphosed bentonitic beds may be unrecognizable because of destruction of the structure by dynamic processes or by re-working and re-deposition of the volcanic materials. For these reasons it is probably impossible to recognize all beds that contain volcanic materials. It is evident, however, that microscopic studies and a comparison of the igneous-rock minerals will allow the identification of many volcanic deposits and add materially to the interpretation of the geologic history of any region.

GAS A BIG FACTOR IN THE TEXAS PANHANDLE[1]

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ABSTRACT

The importance of the conservation of gas in the Texas Panhandle can hardly be overestimated. It affects the oil producer nearly as much as it does the gas producer. The fact that the granite wash and dolomite are in communication and that the oil and gas reservoirs are thus connected means that whatever affects the gas will affect the oil.

In the following paper it is shown that the amount of gas produced at the present time in the Panhandle will deplete the field in 24 years. It is also shown that more than half the gas produced is wasted. If the wastage could be stopped the life of the field might be doubled or even trebled. This would be beneficial to oil and gas operators alike. From recent studies made by John R. Evans we find that, where the gas has been allowed to blow off, the pressure has declined very rapidly and the ultimate production per acre will not exceed 6,000 barrels, whereas if the gas is saved the initial production per well may not be as great, but the ultimate production of oil will exceed 8,000 barrels per acre. It seems clear that by saving the gas in a given locality the oil production may be greatly increased and the cost of cementing an extra string of pipe is not significant compared with the additional recovery of oil obtained by saving the gas.

INTRODUCTION

The discovery of gas in the Texas Panhandle which led to the discovery of oil was due to the efforts of S. F. Sullenberger, Frank Stone, M. C. Nobles, Dr. Cunningham and G. H. Gainer, who formed the Amarillo Oil Company early in 1918 and upon the geological advice of Charles N. Gould drilled Masterson No. 1, which encountered gas in December of 1918. Up to that time no deep holes had been drilled in the Panhandle nearer than the well at the town of Spur in Dickens County. The Empire Gas & Fuel Company were drilling a well in Cimarron County, Oklahoma, about half way between the town of Elkhart, Kansas, and Boise City, Oklahoma. This well was never drilled more than 1,583 feet. From all indications of the structure as worked out from western Oklahoma, it appeared that the Panhandle was underlain with a great thickness of Red-beds. It will be

[1]Published by permission of The Midwest Refining Company and J. H. Clark, vice-president of The Midwest Exploration Company. Manuscript received by the editor, November 26, 1927.

[2]Chief geologist, The Midwest Exploration Company.

remembered that the so-called "Big lime" of the Panhandle[1] does not crop out in Oklahoma; that is, eastward the "Big lime" grades into shale and at the outcrop it consists of Red-beds; hence any prospecting which was carried on in the Panhandle at that time lacked information on the character of the strata at depth,—the Red-beds were considered unfavorable and the Pennsylvanian thought to be too deep. Then, too, much of the area was covered with Tertiary, which concealed the structure of the Permian. Favorable structures were known along Canadian River where the Permian was exposed and had been mapped as early as 1905 by Dr. Gould and a party from the United States Geological Survey.[2]

The discovery of gas in large quantities attracted the attention of many of the oil companies to the Panhandle. As drilling proceeded, arkose and granite were encountered in northern Potter and northern Carson counties. This immediately aroused the interest of the geologists to explain the character of the structure and the trend of production. The nearest granite exposed was in the Wichita Mountains; hence, the first supposition was that the granite of the Panhandle was merely a buried ridge or extension of the Wichita Mountains of Oklahoma. This was disputed by several geologists who attempted to show that the granite in Potter County was an intrusion of Permian age or later; however, accumulated evidence has shown that the granite found in Potter and Carson counties must be attributed to the presence of a chain of mountains which became islands in early Permian time and were then deeply buried by sediments of Permian and Triassic age.

The supposition of the geologists that the Potter County dome was connected with the Wichita Mountains enlarged the prospective territory greatly and drilling along a line between the two areas began in the spring of 1919 with the result that much gas was found but oil was not discovered until the spring of 1921.

CHARACTER OF THE GAS

The gas first discovered and developed along the Panhandle anticline was lacking in gasoline or any of the hydrocarbons which might be used for natural gasoline. In other words, it was known as a dry gas. It was exceptionally high in ethane and several streaks of gas were encountered which were known as poison gas. With the devel-

[1]C. Max Bauer, "Oil and Gas Fields of Texas Panhandle," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 8 (Aug. 1926), pp. 733 and 746.

[2]C. N. Gould, *U. S. Geol. Survey Water Supply Papers 154 and 191.*

opment of oil in Carson and Hutchinson counties it was found that the gas associated with the oil contained considerable gasoline and also that the poison gas was much more plentiful in that area than it was along the axis of the major structure. The poison gas is due to hydrogen sulphide. Since the manufacture of natural gasoline began, many analyses of the gas have been made, with the result that helium has been found at several places in considerable quantity. The gas in central Potter County is especially high in helium and the writer is informed that the western extension of the gas field into Hartley County contains considerable helium. It is also interesting to note that a well drilled about 6 miles west of Adrian in Oldham County encountered gas in five different strata between 1,500 and 2,000 feet in depth and as it did not burn it was called "air" by the drillers. The following is a typical analysis of the gas:

ANALYSIS OF GAS, POTTER COUNTY

	PER CENT
Methane	68.7
Ethane	17.5
Carbon dioxide	.7
Oxygen	.4
Hydrogen sulphide	3.0
Nitrogen	9.7
Heating value	687 B.T.U.

SIZE OF THE FIELD

The accompanying map (Fig. 1) shows in outline the area underlain by gas in commercial quantities; that is, the outline is drawn to enclose only wells of 10,000,000 cubic feet capacity. There are smaller gas wells outside of this area but it is believed that the average of wells inside of this area will be more than 10,000,000 cubic feet. Some of the gas wells have more than 100,000,000 cubic feet capacity. The size of the area of productive gas in the Panhandle as outlined on this map is 1,483 square miles or 949,120 acres. This area is divided into counties as follows: Hartley, 24.8, Hutchinson 197.8, Moore 447.1, Potter 183.0, Carson 295.5, Gray 193.0, Wheeler 138.5, and Collingsworth 3.3 square miles.

By examining a large number of drillers' logs it is found that the average thickness of the gas "pay" in the Texas Panhandle is 36.2 feet. This figure agrees fairly well with a study of samples from some of the wells although the samples indicate that there is some porosity in the dolomite which is not reported as pay sand by the drillers. In

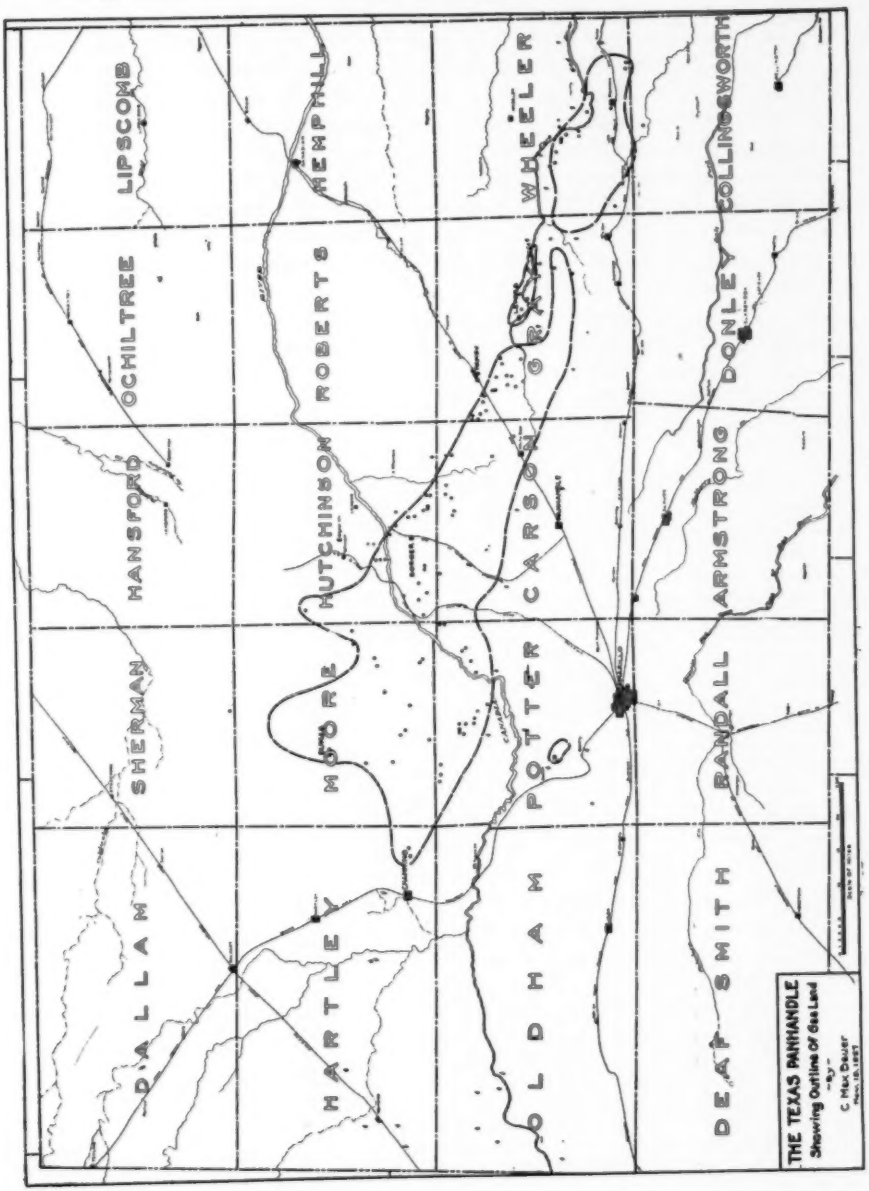
LIPSCOMB
OCHILTREE
HEMPHILL
ROBERTS
WHEELER
COLLINGSWORTH
DONLEY
MANSFORD
HUTCHINSON
CARSON
ARMSTRONG
SHERMAN
MOORE
POTTER
RANDALL
DALLAM
HARTLEY
OLDHAM
SMITH
DEAF
THE TEXAS PANHANDLE
Showing Outline Of Gas Land
-By-
C. Max Bauer

FIG. 1

other words, the portion of the dolomite which is sufficiently porous to produce gas is at least 36 feet in thickness although this occurs in three to seven pay streaks. The following is an estimate by Fred Roth of the thickness of the gas "pay" and of the dolomite in the Texas Panhandle by counties:

THICKNESS OF THE GAS PAY BASED ON DRILLERS' LOGS AND SCOUT REPORTS

COUNTY	NUMBER OF WELLS	TOTAL PAY (FEET)	AV. THICKNESS (FEET)
Carson	39	1704	43.7
Gray	36	907	25.2
Hutchinson	40	1403	35.0
Moore	10	403	40.3
Potter	17	675	39.7
Wheeler	32	1311	40.8
Total	174	6403	
Average pay per well		36.2 ft.	

THICKNESS OF THE DOLOMITE SERIES AS BASED ON DATA FROM SAMPLES AND DRILLERS' LOGS

COUNTY	FEET
Carson	420
Gray	240
Hutchinson	420
Moore	180
Potter:	
(a)	150*
(b)	200**
Wheeler	165

*Gas from true sands above and below dolomite.

**Gas field near Gentry.

ORIGINAL GAS CONTENT OF THE FIELD

The total area of gas in the Panhandle amounts to 1,483 square miles or 949,120 acres. Tabulated by counties the figures are as follows:

SIZE OF GAS AREA

COUNTY	THICKNESS OF GAS PAY (FEET)	SQUARE MILES	AMOUNT (CU. FT.)
Moore	40.3	447.1	50,187,000,000
Hartley	40.0	24.8	2,765 000,000
Potter	39.7	183.0	20,254,000,000
Hutchinson	35.0	197.8	19,498,000,000
Carson	43.7	295.5	36,000,000,000
Gray	25.2	193.0	13,559,000,000
Wheeler	41.0	138.5	15,830,000,000
Collingsworth	40.0	3.3	368,000,000

The average thickness of "pay" is 36.2 feet and the total recoverable gas in the Panhandle before drilling began is estimated at 158,461,000,000 cubic feet at 430 pounds pressure. A small area in central Potter County showed 750 pounds pressure. At one atmosphere pressure the amount is 4,436,000,000,000 cubic feet of recoverable gas. If 500,000,000 feet of gas should be taken from the Panhandle district each day this gas would last for 24 years. In these figures the porosity is taken at 20 per cent and the recovery at 50 per cent. Gas recovery is generally more than this but this gives a conservative figure. If the recovery is figured as high as 80 per cent, which is not unreasonable, the gas will last at this rate for 38.5 years.

As previously stated, the outline on the map encloses only that land that will produce wells of 10,000,000 cubic feet or more daily capacity. The actual capacity of wells already drilled in this area ranges from 10,000,000 cubic feet to more than 100,000,000 cubic feet. The average well will produce about 20,000,000 cubic feet per day. From 15 wells in Potter County we have a daily gauged capacity of 148,536,000 cubic feet or 9,902,000 cubic feet per well. From 12 wells in Carson County we have a daily gauged capacity of 333,000,000 cubic feet or 27,750,000 cubic feet per well. From 4 wells in Hutchinson County we have a daily gauged capacity of 163,495,000 cubic feet or 40,873,000 cubic feet per well. From 7 wells in Wheeler County we have a daily gauged capacity of 233,312,900 cubic feet or 33,304,000 cubic feet per well In addition to this we have a large number of wells in which gas has been shut in, which would add considerably to the total.

The following is estimated capacity of a large number of wells not already included:

CAPACITY OF WELLS

COUNTY	NO. WELLS	TOTAL EST. CAPACITY (CUBIC FEET)	AV. DAILY CAPACITY (CUBIC FEET)
Potter	6	160,500,000	26,750,000
Hutchinson	60	920,000,000	15,333,333
Gray	32	592,000,000	18,500,000
Moore	11	336,500,000	30,600,000
Carson	61	1,370,000,000	22,459,000
Wheeler	23	365,500,000	16,613,000
Total	231	4,502,000,000	19,490,000

The total amount of gas for both estimated and gauged wells gives a daily capacity of 5,380,000,000 cubic feet. Since in general practice

only 20 per cent of the capacity of a gas well is used we obtain an amount of approximately one billion cubic feet of gas available for use at the present time.

The evidence of decline in gas pressure from the original pressure of 430 pounds per square inch is obtained mainly from the Borger district. Here the pressure began dropping rapidly in the summer of 1926 and during the winter of 1926 and 1927 the decline in pressure averaged 20 pounds per month in the heart of the field. Some wells that were making large quantities of gas lost pressure at the rate of 30 pounds per month. In October, 1926, the average pressure on wells between Borger and Dixon Creek was about 320 pounds and by June the average pressure in this area was 160 pounds with some of the earlier wells down to 120 pounds. Gas was wasted in the drilling of wells to an amount of as much as 325,000,000 cubic feet per day for weeks at a time. After the wells were drilled much of this gas was delivered to gasoline plants, and gasoline plants in the Panhandle district how have a capacity of 648,000,000 cubic feet per day. Running at 80 per cent capacity these plants will use 518,400,000 cubic feet, from which the gasoline is extracted and the residue is used in lease operations, drilling, and in carbon black plants. In addition to this amount, it is estimated that 200,000,000 cubic feet daily is being blown into the air, in Hutchinson County alone, which serves no use whatever. It is estimated that a like amount is wasted in the other districts producing oil. Inasmuch as the gas and oil reservoirs are in communication the wastage is detrimental to the whole field. If we assume that the Panhandle is producing and wasting 500,000,000 cubic feet daily at this time we find that the entire reserve of 4,436,000,000,000 will be depleted in 24 years. With additional gas marketed through gas lines now being laid the life of the field will be materially shortened.

The decline in gas pressure in the Borger district is shown graphically in Figures 2, 3 and 4. The data for these curves is taken from the records of three typical leases. The curves shown in Figure 2 are from a lease just east of the town of Borger, and in a part of the field that is near the center of oil production and necessarily also the center of gas production. The wells in this neighborhood were allowed to blow off the gas during the time they were being drilled in and after the completion of drilling have been connected to gasoline plants where this market was available; otherwise the gas continued to waste. The average decline of four wells from 280 pounds to 100 pounds in 12 months certainly gives food for thought, as it is this gas pressure which

is bringing the oil into the well and which is directly comparable with the production of oil. The difference between the original field pressure of 430 pounds and these first recorded pressures represents the loss which came between the discovery of the field and the starting of active

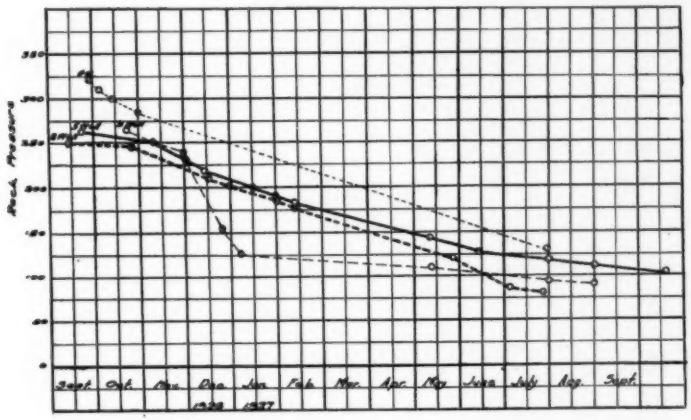

FIG. 2.—Rock-pressure decline on a property near center of Borger district, Hutchinson County field.

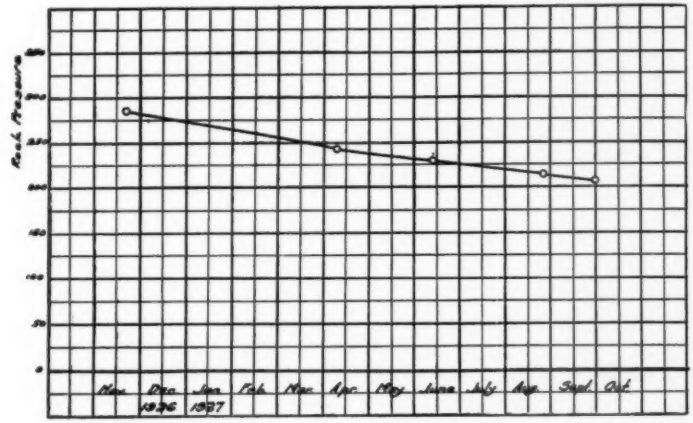

FIG. 3.—Rock-pressure decline on a property at the northwest edge of the Borger district, Hutchinson County field.

operations on a large scale in September, 1926. The slight flattening of the curve in its later stages is perhaps due to the gas conservational methods of some of the operations and, in some measure, to the infiltration of gas from the high-pressure areas.

Figure 3 shows a decline in pressure on a lease just east of Electric City in the northwest part of the Borger district. This decline from 280 pounds to 207 pounds in ten and one-half months is very favorable as compared with the declines shown in Figure 2 and is attributed to

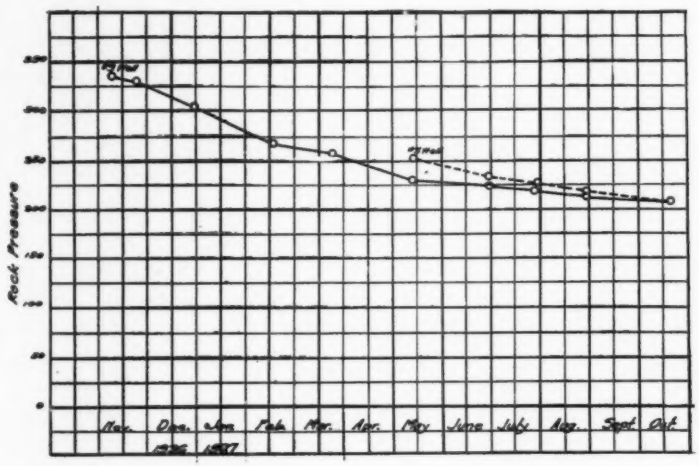

FIG. 4.—Rock-pressure decline on a property at the west edge of Borger district, Hutchinson County field.

less wastage and a lack of drilling to the north. This high pressure area adjacent to the lease, and the influx of gas to the area depleted by drilling, has held the decline well above the average.

Figure 4 shows a decline in pressure of two wells on a lease at the west edge of the Borger district, namely, along the west side of section 21. It shows a decline from 335 pounds to 207 pounds in eleven and one-half months, which also compares favorably with declines in the center of the field. The same explanation of this difference as was advanced for Figure 3 is believed to hold true in Figure 4, with the exception that the high pressure area is on the west.

As the pressure in some of the wells of the Borger district is now down to 100 pounds or less, the pressure in the Sanford area down to

350 pounds, and that in the Pampa pool down to 275 pounds, it is evident that a decline has set in which will affect the whole Panhandle. It is true that when the pressure is greatly reduced in one district the differential pressure between it and the main reservoir causes a movement of gas from the main reservoir to the area of low pressure. This slows up decline somewhat, even when the amount of gas taken from the reservoir is not diminished. It is a serious problem for both oil and gas producers to face. Pressure is the key to the whole situation in producing gas and oil. When it is understood that the quantity of gas in the reservoir is directly proportional to the pressure it is seen that when the pressure is off 75 per cent the quantity of gas is likewise depleted 75 per cent,—though, of course, some of the gas may be replaced by migration from adjacent areas.

FUNCTION OF GAS IN PRODUCING OIL

As already indicated, pressure in the sand is the life of an oil field as well as a gas field. From our experience we know that sand pressure or rock pressure is essential to the efficient operation of the gas or air lift; when the sand pressure is gone the lift no longer functions and with decrease in sand pressure the lift becomes increasingly difficult until the balance of intake and sand pressure becomes so delicate that continuous flowing is not effective and periodic blowing is resorted to. When this stage is reached, it is usually just as economical to put the well on the pump. Then, even with the well on the pump, a low pressure in the sand is a decided handicap, and with the pressure gone the well becomes a "stripper" although much oil may still remain in the sand.

Recently Beecher and Parkhurst[5] have made experiments to show the effect of dissolved gas upon the viscosity and surface tension of crude oil. Their results showed that the amount of gas dissolved is directly proportional to the pressure, other things being equal; also that the viscosity of crude oil is greatly reduced when oil contains gas in solution. The decrease in viscosity depends upon the amount of gas dissolved in the oil if other conditions are constant, and an oil with high initial viscosity will show a greater relative decrease for a given amount of dissolved gas than one with a lower initial viscosity.

A similar result was found with regard to the effect of dissolved gas on surface tension. They state that

[5] "Effect of Dissolved Gas upon the Viscosity and Surface Tension of Crude Oil." *A. I. M. E., Petroleum Development and Technology in 1926*, pp. 51-63.

a large percentage of oil which present production methods fail to remove from the sands is held by capillarity. As the gas dissolved in the oil escapes, the surface tension is increased and, likewise, the capillary force which is a measure of surface tension. If this increase in surface tension could be prevented during the process of extracting the oil from the sands, a greater volume of oil should be recovered.

Another function of the gas in producing oil is particularly applicable to the Panhandle. This is its ability to hold back the water. It is well known that the pressure in the oil, gas, and water in the Panhandle was in equilibrium in the early days of the field. Removal of the gas and oil has disturbed this balance and caused the water to rise locally. Of course, the gas is expansible and the oil with dissolved gas is also somewhat expansible but the water is not expansible or compressible. However, with the maintenance of pressure at one point and the release of pressure at another such as happens when a well is drilled in, the water will cone up at the well and by so doing cut off part of the oil sand. If pressures could be maintained or their decline retarded, water coning would be retarded. Nearly all water troubles in the Panhandle are the result of coning of bottom water, hence preservation of the gas will greatly reduce water troubles.

SAVING THE GAS

With approximately one billion cubic feet of gas available for the market and with an estimated daily wastage of three hundred to four hundred million cubic feet it is incumbent upon oil operators to save gas wherever it is possible to do so. During the rush of early development in the field many wells were not cased through the gas "pay" and if the pipe was run it has been shown that many of these wells failed to shut off the gas. Much of it comes around the shoe of the gas string which is merely hanging in the hole. Other examples are known of the gas string being pulled up to admit more gas into the hole with the belief that in so doing more oil would be produced. It is true that if the oil is available, increased gas will mean increased oil production; however, it has also been shown for the Panhandle field, that with the proper size tubing any amount of gas greater than 3,500 cubic feet per barrel of oil produced is not only unnecessary but detrimental to the production of oil. In other words, if a well of given size is properly tubed, anything in excess of 3,500 cubic feet per barrel of oil produced will cause "blowing" of the gas which means that a part of the gas is replacing or by-passing the oil which should be lifted from the hole. At any rate, there are many wells which might be repaired by lowering

the casing, or by using a packer, or by cementing in such a way that the gas could be conserved and the oil produced without waste. We need make no statement here as to the importance of gas conservation to the gas producer. To him, a loss of gas is a direct loss and a decrease in pressure means additional expense in marketing.

Many operators have contended that gas wastage could not be avoided while drilling through the gas pay. This is not strictly true, for it has been demonstrated in the Panhandle field, where the pressure of the gas is below normal, that it is possible to drill through the gas by balancing the water in the hole with the pressure of the gas in such a way that very little gas will be wasted. This method, invented by N. O. Miller, has been tried on several occasions and found workable. In many circumstances it will save time and money for the operator as well as saving gas. It is recommended that this method be investigated and if found satisfactory be used in drilling through gas, especially wherever big gas is encountered.

By the repairing of wells in the main producing areas it seems probable that the influx of gas from the surrounding territory will retard the decline of pressure appreciably. In addition to this, it is suggested that residue gas which is not used might be returned to the gas sand in wells which are now dead. Although this suggestion may be regarded as untimely, the writer believes it will not be long until it may be necessary to resort to this method to restore the pressure in order to get out a fair proportion of the oil which still remains in the producing area.

THE SALINA BASIN OF NORTH-CENTRAL KANSAS[1]

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El Dorado, Kansas

ABSTRACT

The Salina basin, a pre-Pennsylvanian structural feature lying in north-central Kansas between the Nemaha granite ridge and the Barton arch, is shown to contain a thick pre-Pennsylvanian section. This section is divided into seven distinct lithologic units, three of which are definitely correlated with known strata elsewhere, and four given new names applicable in the Salina basin. The Welch chert as described by Moore is concluded to be a deposit of residual chert formed in place from the "Mississippi lime."

INTRODUCTION

The most prominent structural features of the pre-Pennsylvanian strata of eastern and central Kansas are shown on the accompanying sketch map (Fig. 1).

The Chautauqua arch is here suggested as a name for the pre-Mississippian extension of the Ozark uplift along the Kansas-Oklahoma line. White[3] has demonstrated the presence of the south flank of this high in northeast Oklahoma. Subsurface work in Kansas by the writer has defined its crest and north flank.[4]

The name Barton arch is here suggested for the broad pre-Pennsylvanian and probably in part pre-Mississippian high in Ellsworth, Rice, Barton, Russell, and near by counties. The presence of Ordovician strata directly underneath the Pennsylvanian in Russell County has been demonstrated by Udden[5] and Twenhofel.[6] This arch is in line with the Chautauqua arch and is separated from it by a gentle saddle.

[1]Manuscript received by the editor, December 1, 1927.

[2]Geologist, Skelly Oil Company.

[3]Luther H. White, "Subsurface Distribution and Correlation of the Pre-Chattanooga Series of Northeastern Oklahoma." *Oklahoma Geological Survey Bull. No. 40-B*, 1926.

[4]Paper in preparation.

[5]Jon. A. Udden, "Occurrence of Ordovician Sediments in Western Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. X (1926), p. 634.

[6]W. H. Twenhofel, "Ordovician Strata in Deep Wells of Central Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XI (1927), p. 49.

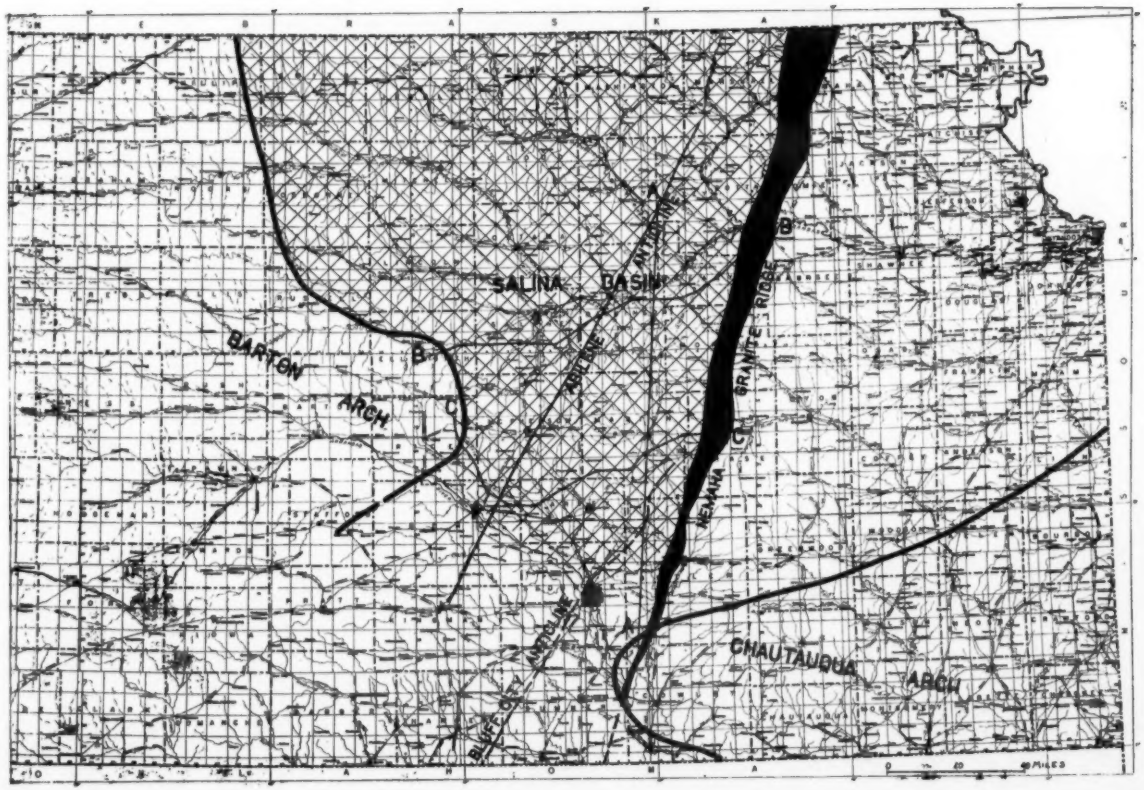

FIG. 1.—Prominent structural features of the pre-Pennsylvanian strata of eastern and central Kansas. U. S. Geological Survey base map.

The Nemaha granite ridge is a major line of anticlinal folding trending in a direction slightly east of north, in which pre-Cambrian rocks locally approach the surface closely. Moore[1] has described the ridge in detail.

The Abilene anticline is another fold of considerable size trending slightly more east than the granite ridge. The McPherson gas field has recently been discovered upon it.

The Bluff City anticline, which approximately parallels the Abilene anticline, extends from the Florence-Urschel field in Marion County through the Elbing field in northwest Butler County to Bluff City in southeast Harper County.

The Salina basin is herein defined as the pre-Pennsylvanian syncline bounded on the east by the Nemaha granite ridge, on the southwest by the Barton arch, and on the south by the saddle between the Chautauqua arch and the Barton arch. The basin continues northward into Nebraska, where its exact termination is unknown. The Abilene anticline and the north end of the Bluff City anticline are its most prominent structural features.

The writer is indebted to the Skelly Oil Company for permission to publish this paper. Thanks are due to J. R. Reeves and H. D. Mueffels of the Empire Oil & Refining Company, for their aid in the interpretation of drill cuttings and logs in the area.

PREVIOUS LITERATURE

Aurin, Clark, and Trager[2] showed, in 1921, that Ordovician strata correlated by them with the Tyner formation and the "Siliceous lime" of the Oklahoma section directly underlie Pennsylvanian rocks on the crests of some of the producing oil fields of northwest Butler and southeast Marion counties.

M. N. Bramlette[3] in 1925 published a cross-section from Marion County to Russell County, which crossed the area of the Salina basin. In this section a horizon considered to be the "Mississippi lime" was recognized in four wells, including the zone from 3,270 to 3,370 feet

[1]R. C. Moore, "Geologic History of the Crystalline Rocks of Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. II (1918), p. 112.

[2]Aurin, Clark and Trager, "Notes on the Subsurface Pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. V (1921).

[3]M. N. Bramlette, "A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas." *State Geological Survey of Kansas, Bull. X*, Part 2.

in the Sheridan well in Sec. 21, T. 15 S., R. 6 W., Ellsworth County. The finding of Pennsylvanian fossils at a depth of 3,500 feet in this well was mentioned, but the conclusion was reached that they were not in place. The pre-Mississippian strata were not discussed in detail.

H. A. Ley[1] in 1926 presented three short notes in which he stated that the "Mississippi lime" had been found to be present west of the granite ridge in western Butler, Sedgwick, and Harvey counties; and that the cherty horizon in the Sheridan well, based on well-to-well correlations, was the equivalent of the Oswego lime of the surface section of southeast Kansas.

R. C. Moore[2] shortly afterward published a paper in which he expressed the belief that the fossils from the Sheridan well were representative of the depth from which they were purported to have come. Basing his conclusions on this fossil occurrence, he presented an ingenious theory on the origin of the "Welch chert," the producing horizon in the Welch oil pool of Rice County. In brief, he considered that after the initial uplift of the granite ridge in post-Mississippian time, the area was base-leveled; that Pennsylvanian shales of a thickness up to about 200 feet were deposited; that after this deposition there was another uplift of the granite ridge, followed by the erosion of cherty material from the ridge and its deposition westward. Moore did not discuss the strata below the shales underlying the Welch chert, except to mention that he considered them in part Mississippian and in part Ordovician.

Since the appearance of Moore's paper, it has been the tendency of geologists working the area to use his correlations. Anthony Folger spoke on the Welch chert at the Lawrence meeting of the Kansas Geological Society in November, 1926; and Roy Hall discussed the same subject at the March, 1927, meeting of the Kansas Geological Society at Wichita. Both of them pointed out some facts which did not agree with Dr. Moore's theory, but finally concluded that it was largely correct.

STRATIGRAPHY

The section encountered in the area of the Salina basin ranges in age from Quaternary to pre-Cambrian. As the structural and stratigraphic problems with which this paper is concerned manifest them-

[1]H. A. Ley, "Mississippi Lime West of the Granite Ridge in Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. X (1926), p. 92; *idem*, "Age of Producing Horizon, Rice County, Kansas" and "The Sheridan Test, Ellsworth County, Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. X (1926), p. 197.

[2]R. C. Moore, "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge, Kansas." *Bull. Amer. Assoc. Petrol. Geol.*, Vol. X (1926), pp. 205-34.

selves in that portion of the section below the Kansas City-Lansing limestone subdivision of the Pennsylvanian, the higher strata will not be discussed here. The strata down through the Kansas City-Lansing can be correlated readily with those which outcrop in eastern Kansas.

The conclusions advanced in this paper were based on a study of the lithologic character of drill cuttings from a great number of wells in the area. From this study an interpretation of the logs of other wells from which samples were not available was made.

LOWER PENNSYLVANIAN

The Marmaton formation in southeastern Kansas consists of dark-colored shales, with several thin limestones and here and there a lenticular sandstone. In the area just east of the granite ridge, red, green, and purple shales, the "variegated" shales of the drillers, become noticeable. As we pass northwest into the Salina basin these colors become dominant. Limestone and sandstone remain a minor part of the formation, and some conglomeratic material is present at its base.

The Cherokee shale is absent in the northern part of the basin, and only its uppermost portion is present to the south. This portion resembles the Marmaton very closely, consisting of gray, red, and green sandy shales and some conglomeratic material.

PRE-PENNSYLVANIAN

The pre-Pennsylvanian of the Salina basin is readily divisible into seven distinct lithological units. Three of these, because of their continuity and persistent character, are given the names applied elsewhere in the north Mid-Continent. The other four units are of more doubtful correlation, and will probably remain so for some time to come. As some system of nomenclature is necessary, these units are given new formation names and subsurface type localities. The writer feels that for the present petroleum geologists working in the state can proceed with their subsurface work with much more confidence if they use the nomenclature herein suggested than if they attempt sketchy long-range correlations.

A generalized north-south section showing the lower Mississippian and pre-Mississippian strata of the Salina basin is shown in Figure 2. The base of the Mississippian is used as datum in the section. The upper surface of the "Mississippi lime" is not shown, as its irregularities would only be confusing in a section of this kind.

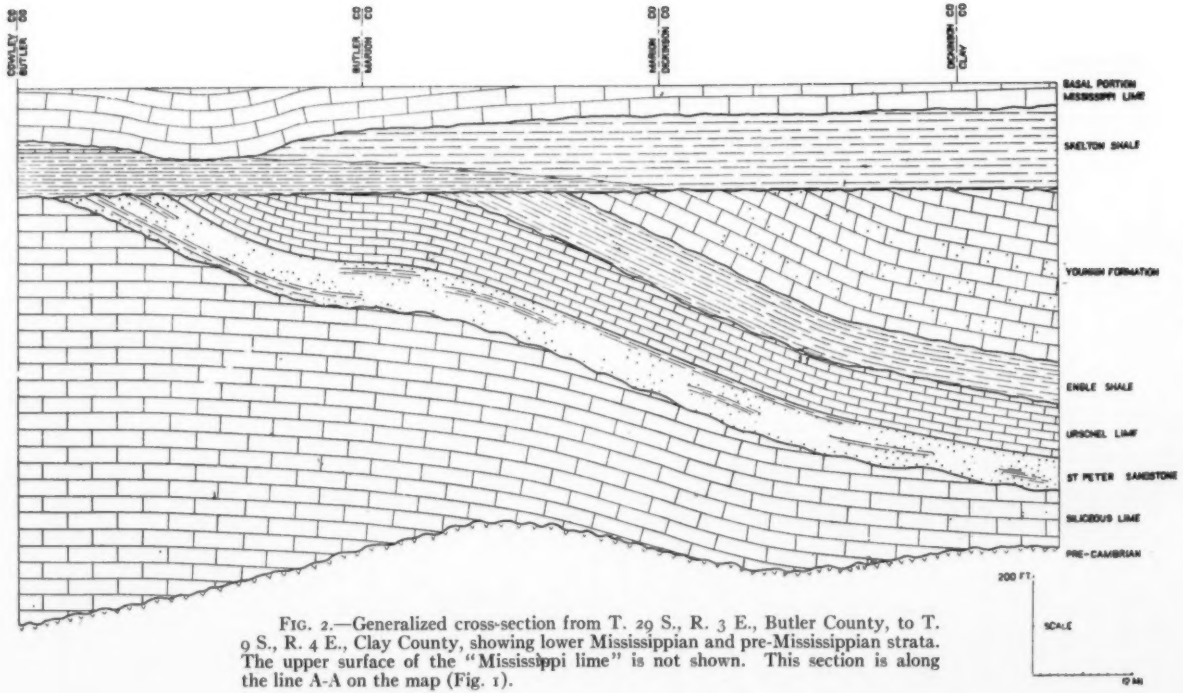

FIG. 2.—Generalized cross-section from T. 29 S., R. 3 E., Butler County, to T. 9 S., R. 4 E., Clay County, showing lower Mississippian and pre-Mississippian strata. The upper surface of the "Mississippi lime" is not shown. This section is along the line A-A on the map (Fig. 1).

Unit 1 is a white to gray cherty lime ranging from a few to 300 feet in thickness. Well-to-well correlations from the Oklahoma-Kansas line northward prove that this unit represents the "Mississippi lime" of the north Mid-Continent.

Studies by Van Tuyl[1] in Iowa and Buchanan[2] in Oklahoma indicate that the Boone cherty limestone member of the Mississippian pinches out to the northwest in those states, and that in the same direction the St. Louis cherty limestone member makes up the greater portion of the "Mississippi lime". It seems possible that such a change is regional rather than local, and that the same northwesterly change takes place in northern Kansas. If this be so, then the cherty lime in the Salina basin is the St. Louis; but, on the basis of lithology, it can only be said that it may represent either the Boone or the St. Louis, or parts of both. As the term "Mississippi lime" has been long used to denote this horizon elsewhere in the state, and as it is entirely correct, it is recommended that it be used in the Salina basin. The "Welch chert" as described by Moore will be considered later in this paper.

Unit 2, which is 100 to 150 feet in thickness over most of the basin, comprises the thickest shale zone below the Pennsylvanian. In a wide belt passing through Marion, McPherson, Rice, and Reno counties it rests directly on Unit 4, and the two form the 200- to 250-foot shale zone which numerous wells have penetrated. Unit 2, at the south end of the basin, consists of about 70 feet of black fissile shale, which correlates with the Chattanooga. Northward, the black shale zone thins or fingers out. Above this zone in southern Kansas are patches of gray, green, and red shales and thin limes. Northward into the Salina basin, the gray, green, and red shales thicken rapidly until they occupy the entire 150-foot thickness of the zone. The work of Van Tuyl and Buchanan, previously referred to, suggests that these shales are of Kinderhookian age. On its outcrop in the upper Mississippi River valley the Kinderhookian is much subdivided, and exact correlation with any of its members is impossible at this time. It is therefore suggested that Unit 2 in the Salina basin be named the Skelton shale, after Danciger Oil & Refining Company, Skelton No. 1 in Sec. 26, T. 15 S., R. 2 W., Saline County, which encountered this horizon at a depth of 3,085 to 3,205 feet.

Unit 3 consists of white to gray dolomitic limestone locally inter-

[1] *Iowa Geological Survey*, Vol. 30, 1919.

[2] George S. Buchanan, "Distribution and Correlation of the Mississippian of Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. II, No. 12 (December, 1927).

bedded with thick, probably lenticular, bodies of rounded quartz sand in a lime matrix. In at least one well it contains a black crystalline limestone bed. The whole zone attains a thickness of 400 feet or more in Clay and Riley counties. The lithology and position of this zone suggest a correlation with the Silurian and Devonian rocks penetrated by deep wells in southeast Nebraska, southwest Iowa, and northwest Missouri, in which diagnostic fossils were found by Ulrich. The beds encountered in the Missouri wells previously mentioned have not been correlated exactly with beds outcropping in Missouri and Iowa, but Ulrich[1] considers them to be Middle Silurian and Middle and Upper Devonian. They do not correspond in age to the members of the Hunton limestone of Oklahoma, which are Lower Silurian and Lower Devonian.[2] Unit 3 is therefore given the name of Younkin formation after Boggess *et al.* Younkin No. 1, in Sec. 21, T. 9 S., R. 4 E., Clay County, which well encountered this horizon at a depth of 2,194 to 2,520 feet. Drill cuttings are not available from this hole, and the name Younkin was chosen for this formation because the farm names of holes in which a considerable thickness of the horizon was encountered and samples saved are preoccupied.

Unit 4 consists typically of light-colored fine-grained shales, generally with a bluish-gray or greenish-gray cast. It contains in places a small amount of dolomitic lime or very fine-grained quartz sand silt. Normally where overlain by the Younkin formation it has a thickness of 60 to 100 feet. The lithologic character and stratigraphic position of this zone indicates that it correlates approximately with the Sylvan shale of Oklahoma and the Maquoketa shale of Iowa and Missouri. Ulrich considers that the Sylvan and Maquoketa are correlatives, while others hold that the Maquoketa is uppermost Ordovician and the Sylvan Lower Silurian. The writer is therefore suggesting the name Engle shale for this unit, after Marland Oil Company, Engle No. 1, in Sec. 12, T. 14 S., R. 1 E., Dickinson County, in which this unit was found at a depth of 2,876 to 2,962 feet.

Unit 5 is a white to brown, commonly cherty, dolomitic limestone ranging from a few feet to more than 135 feet in thickness. It appears to correlate approximately with the Viola limestone of Oklahoma, but is lithologically dissimilar from the two members of the Viola present in northern

[1]E. O. Ulrich, "Correlation of Strata from 2,041 to 2,500 feet in Forest City Core Hole, Holt County, Missouri." *Missouri Bureau of Geology and Mines*, Vol. XIII (1915), pp. 234-39.

[2]Chester A. Reeds, "The Hunton Formation of Oklahoma," *Am. Jour. Sci.*, Vol. 32 (October, 1911).

Oklahoma. It must also be equivalent to a part of the Plattin-Kimmswick section of Missouri, and the Platteville-Galena section of Iowa. As the exact correlations of these beds have not been worked out even on the outcrop, the writer again feels that a local name is necessary. The name Urschel lime is therefore suggested. This unit is one of the principal pre-Mississippian oil-producing horizons in the state. Some of the production in the old El Dorado field of Butler County is coming from this lime, and it forms the main oil-producing horizon of the Florence-Urschel field of Marion County, where it is approximately 100 feet in thickness. The Elbing field of northwest Butler County and the Peabody and Covert Sellers fields of southeast Marion County are probably also producing partly from this limestone, but lack of drill cuttings in these pools prevents a definite statement. The pre-Chattanooga pools near Leon, Butler County, produce from this horizon, but here it is only 5 to 10 feet in thickness, and is far from typically developed.

Unit 6 consists predominantly of rounded-to-angular quartz sandstone, containing at different horizons fairly persistent lenses of green shale as much as 20 feet in thickness. In Butler County, the green shale is chiefly near the base of the formation; in Reno County, it is near the top. Locally thin beds of oölitic hematite are present. Where covered by the Urschel limestone, the thickness of the formation ranges from 40 to 120 feet, averaging about 70 feet. This horizon is very similar lithologically to the St. Peter sandstone[1] of Minnesota, Illinois, Iowa, Wisconsin, Missouri, Arkansas, and northeast Oklahoma, and appears to occupy the same stratigraphic position. The St. Peter is the one horizon whose correlation is definitely accepted by almost all geologists of these states. As there is very little doubt that the horizon here described in the Salina basin is the equivalent of the St. Peter, it is recommended that it be called by this name. The St. Peter is believed to be the equivalent of some member of the "Wilcox series" of the northern Oklahoma subsurface section, and of the Simpson formation of the Arbuckles.

Unit 7 consists of cherty dolomitic limestone with a few thin streaks of rounded quartz sand. It thins rapidly northward across the state, from a thickness of 900 feet in southwest Butler County to 200 feet in Clay County. As it is unconformably overlain by the St. Peter, it can be correlated with some portion of the Arbuckle limestone

[1]C. L. Dake, "The Problem of the St. Peter Sandstone." *Bull. School of Mines and Metallurgy, University of Missouri*, August, 1921.

of Oklahoma, with a portion of the Jefferson City and lower beds of Missouri, and the Prairie du Chien and lower beds of Iowa. Due to its rapid northward thinning, and the unconformities both at its top and base, it is not known what portions of the outcropping sections are represented in the Salina basin. It is suggested that the term "Siliceous lime" be retained at least temporarily. This term is at present in very general use, and is satisfactory if the true "Siliceous lime" is not confused with the Urschel limestone and the Younkin formation, as it has been in the past.

STRUCTURE

The Salina basin is due to two distinct periods of folding: first, the uplifts of the Chautauqua arch and the Barton arch in the interval between Devonian and Mississippian deposition; and second, the uplifts of the granite ridge and the Barton arch in the interval between Mississippian and Pennsylvanian deposition. The first uplifts gave the pre-Mississippian strata a dip into the Salina basin which ranges from northeast through north to northwest, and averages about 5 feet per mile. Subsequent peneplanation removed most of the beds from the crests of the arches. Following the deposition of the Mississippian strata, the second uplifts resulted in dips into the center of the basin from both the Barton arch and the granite ridge. These dips, combined with those already present on the pre-Mississippian rocks, gave these older strata the structure of a northward-plunging syncline. Post-Pennsylvanian uplift of the granite ridge and Barton arch and the westward tilting of the entire area has not greatly altered the general character of this syncline. Figure 3 gives two approximately east-west sections across the Salina basin, using sea-level datum. Formations above the Kansas City-Lansing limestone group are not shown. The greatest difference between the two sections is that the Engle shale and the Knight formation are well represented in Section B-B and largely absent in Section C-C.

ORIGIN OF THE WELCH CHERT

The writer's studies lead him to believe that the cherty material in the Salina basin can be divided into two classes: (1) chert of remarkable purity and constancy in stratigraphic position, ranging gradually in thickness from a few feet to 150 feet and resting either directly on the "Mississippi lime" or on the top of the Skelton shales; (2) heterogeneous material consisting largely of chert, but with considerable rounded-to-angular quartz sand, some granitic material, and much

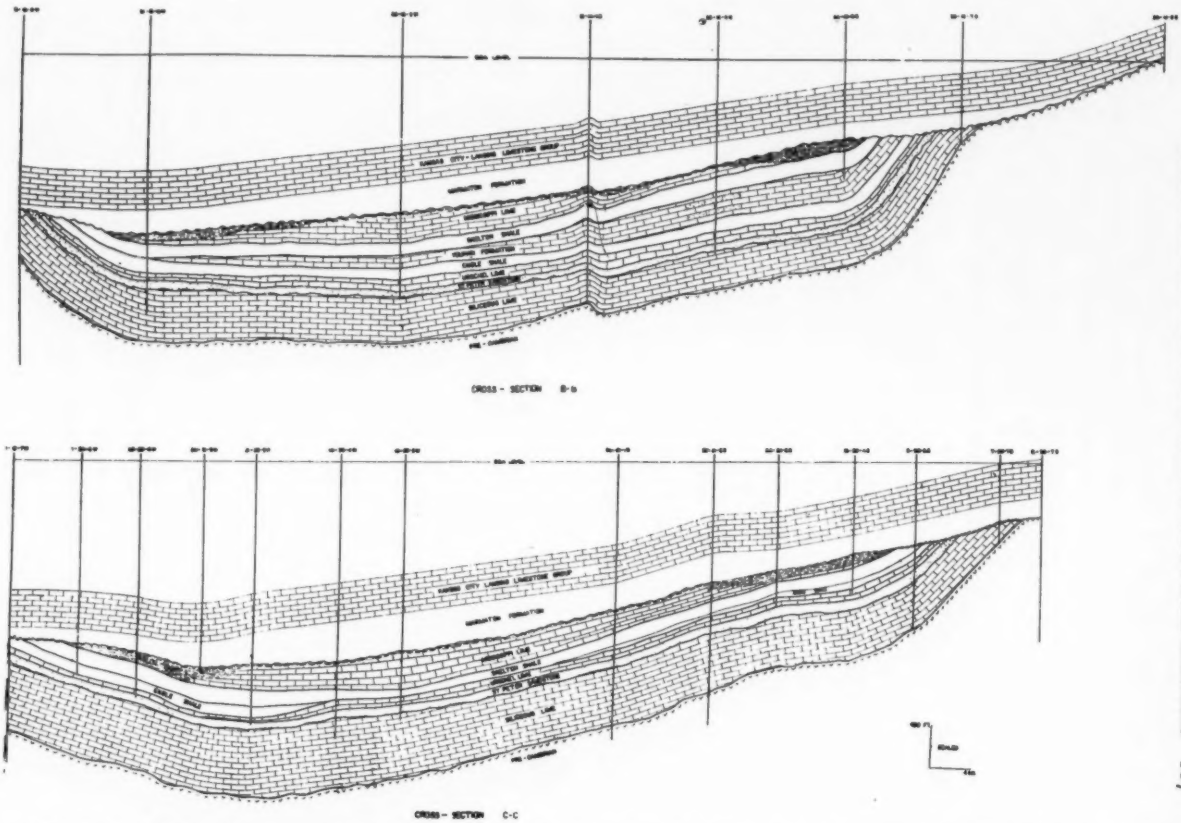

FIG. 3.—East-west sections across the Salina basin, showing formations below the top of the Kansas City-Lansing limestone group. These sections are along the lines B-B and C-C on the map (Fig. 1).

admixed shale, ranging in short distances from almost nothing to as much as 15 to 20 feet in thickness and resting on the pre-Pennsylvanian erosional surface. The cherty material in the Welch pool, which forms the type locality for the Welch chert, is of the first class, unless it be for a few feet at the top of the horizon. The second class is more readily recognizable where it does not directly overlie material of the first class. It is present in variable thickness on the flanks of the Salina basin and well up onto the Barton arch.

The writer's view of the time and manner of origin of these materials, which differs greatly from that of Dr. Moore, is as follows. The uplift of the granite ridge and Barton arch in the interval between Mississippian and Pennsylvanian deposition also resulted in the "Mississippi lime" in the lowest part of the Salina basin being raised above the level of the surface of the "Mississippi lime" east of the ridge. Erosion followed, which very nearly base-leveled the area, but which left it with a southeastward slope. Pennsylvanian deposition began in southeastern Kansas, and the seas gradually advanced northwestward. During early Cherokee deposition in eastern Kansas, the area of the Salina basin was beyond the limits of the sea, but so nearly base-leveled that mechanical erosion and transportation were almost impossible. Conditions were then ideal for the action of ground water on the cherty limes exposed in the basin. The soluble carbonates in the limestones were dissolved and replaced by silica in the form of chert. This process had its greatest effect on the "Mississippi lime" on the flanks of the basin, where the entire thickness of the "Mississippi lime" was altered and residual cherts as much as 150 feet in thickness were formed. The northwestward advancing seas covered the Salina basin in late Cherokee and early Marmaton time. Their initial deposit was a basal conglomerate, which, like the floor over which they were advancing, consisted largely of chert, but contained also considerable quartz sand and granitic material. Above it were deposited the varicolored shales and thin limes of the Marmaton.

The foregoing theory is based on the lithologic character of the materials involved in the Salina basin. The formation of residual cherts in the manner described is discussed by Twenhofel.[1] The writer knows of few figures in the literature as to possible thickness. However, Josiah Bridge, of the Missouri School of Mines, states[2] that he and C. L. Dake, of the same institution, have found that a thickness of 100

[1]W. H. Twenhofel, *A Treatise on Sedimentation*, pp. 184 and 393.

[2]Josiah Bridge, personal communication.

feet of residual cherts is quite common in the Ozarks of Missouri; and that three core holes in Madison County, Missouri, penetrated approximately 180 feet of residual cherts before reaching bed rock. These figures make it apparent that the cherts of the Salina basin are not too thick to have been formed in the same way.

The only strong evidence not in agreement with the writer's theory is that of the Pennsylvanian fossils found by Moore in the Sheridan well. It is noteworthy that in his original paper Moore states that the fossiliferous shale samples were very dissimilar to the shales both above and below. The only logical conclusion is that the fossils are not representative of the horizon from which they are supposed to have come.

CONCLUSIONS

1. The structure of the Salina basin has resulted in the preservation of a thick pre-Pennsylvanian section.

2. The pre-Pennsylvanian sediments are divisible into seven distinct lithologic units, consisting of: (1) "Mississippi lime"; (2) Skelton shale; (3) Younkin formation; (4) Engle shale; (5) Urschel lime; (6) St. Peter sandstone, and (7) "Siliceous lime," which rests on the pre-Cambrian metamorphic and igneous rocks.

3. The Welch chert as described by Moore is a residual deposit formed by the removal of the more soluble portions of the "Mississippi lime" during the erosional interval prior to initial Pennsylvanian deposition in the area.

DISCUSSION

RAYMOND C. MOORE: Stratigraphic evidence concerning the sub-surface conditions in central Kansas has been constantly accumulating. Mr. Barwick's paper is a valuable contribution to the delineation of the interesting conditions in this portion of Kansas. Cuttings representing at least the deeper portions of wells now being drilled are fortunately being saved for the most part and these afford a definite basis for sub-surface study which has not previously been available.

The unit which I have designated Welch chert consists essentially of weathered chert with more or less admixed clay, quartz sand, and other material suggestive of long exposure and decay. In part, this deposit is clearly re-worked and this material, though derived from older rocks, is assignable to the Pennsylvanian. However, the considerable thickness of pure chert, finely ground in some of the cuttings, is evidence in support of Mr. Barwick's conclusion that the chert is a residue derived from a cherty limestone, presumably the Mississippian. The fairly widespread distribution, uniformity in lithological character, and the probable size of the unbroken chert masses underground favor the hypothesis of formation in place by slow solution

and weathering as presented by Mr. Barwick rather than the hypothesis of transportation under conditions of moderately low relief from areas on the border of the basin. The assignment of the Welch chert to the Mississippian is strengthened in my judgment by the discovery of lower Mississippian fossils at the base of the chert in the Ucker well in Marion County. The overlapping of heterogeneous decomposition products which is observed westward into Barton County, may in part represent overlap of Mississippian rocks as inferred by Mr. Barwick and in part may constitute deposits of early Pennsylvanian age which are known to have been laid down in this region.

Chert encountered in the Sheridan well, Sec. 21, T. 15 S., R. 6 W., Ellsworth County, at a depth of 3,270 feet, appears from stratigraphic position and lithologic character to represent the Welch chert. Fossils from a depth of about 3,500 feet are clearly of Pennsylvanian age and I have elsewhere[1] discussed them in some detail. There are presented reasons for believing that the fossils came from the shale at the depth indicated. At the time the fossils were referred to me for identification it was supposed that they were probably Ordovician fossils. Since casing was landed in the chert the fossils hardly appeared possibly to have come above the chert. There are no outcrops of Pennsylvanian or Permian rocks in several miles from the location of the well and there is no reason to suppose that the material was dumped into the well or that the samples in some way became mixed. I am especially convinced of this because at the time of drilling Mr. Keys made a special trip to Lawrence with samples of the cuttings and a fragment brought up on the bailer. Opposed to the single evidence from this well is the fact that no fossils have as yet been found in other wells in shales below the chert. I personally have examined cuttings from the Hartman-Skaer Dunn No. 1, Sec. 28, T.23, R. 8 W., the Brothers Stearns-Streeter No. 1, Sec. 17, T. 21, R. 6 W., the Mississippi Valley Trotter No. 1, Sec. 34, T. 21, R. 7 W., and several other wells in this region. In none of these have fossils been found in the shale below the chert.

ROY H. HALL: Mr. Barwick has placed a somewhat different interpretation on the age and origin of the Welch chert from that of R. C. Moore in his paper entitled "Early Pennsylvanian Deposits West of the Nemaha Granite Ridge, Kansas," published in the *Bulletin of the American Association of Petroleum Geologists*, Volume 10, Number 3 (March, 1926). While Mr. Barwick presents some very good evidence of the residual origin of the Welch chert there are a few points which he failed to consider in his study.

Interpretation of drillers' logs is, of course, sometimes quite difficult and unless one knows all the details of where casing was set, tops and bottoms of formations, etc., a wrong conclusion may be drawn from an examination of well cuttings. The danger of mixture of samples or wrong labeling is always present. However, interpretation of drillers' logs without cuttings is perhaps even more likely to be erroneous. The drillers' log should be supplemented by a study of well cuttings and fossils, if any are found. Taking these points into consideration, positive evidence based on examination of cuttings from one well may not be conclusive evidence for an entire area.

[1]This *Bulletin*, Vol. X (1926), p. 209.

In the section we have prepared to accompany this discussion (Fig. 4) cuttings have been examined from six of the nine wells represented. We have had access to these determinations and have used them together with the drillers' logs in making the correlations shown.

The post-Mississippian, pre-Pennsylvanian uplift which elevated the Barton arch was followed by an extended period of erosion. The Mississippian formations were eroded from the crest and well down the flanks of the arch. Before the time of advance of early Pennsylvanian seas over the area the topography had been practically reduced to a peneplain. The Ordovician dolomites no doubt formed low hills on the west succeeded eastward for some distance by a more or less flat plain where the Ordovician, Chattanooga and Kinderhook shales were exposed. East of this plain the outcrops of Mississippian limestones rose in low-lying hills. The topography, therefore, must have been trough-like, the plains portion being bounded both east and west by low hills. The early Pennsylvanian sea advancing northward from Oklahoma occupied the trough, re-working the exposed shale formations, to some extent. Mississippian shales were mixed with "Wilcox" sand grains and other debris. Ordovician shales and dolomites were also re-worked by the advancing sea. The first thin Cherokee formations laid down were predominantly shale where underlying shales were exposed, and re-worked shales and chert conglomerate mixed with sand and shale where Ordovician and Mississippian dolomites, limestones, and cherts were exposed. On the Barton arch the basal Pennsylvanian conglomerate was laid down in the advancing sea but is progressively younger westward as higher topography was inundated. This explains why the Welch chert or basal Pennsylvanian conglomerate converges westward with the top of the Lansing-Kansas City limestone group.

Instead of assigning a residual origin to the Welch chert and classing it as Mississippian we are inclined to correlate it with the basal conglomerate of the Pennsylvanian in western Kansas and class it as of sedimentary origin. Quite probably a condition existed along the west flank of the Nemaha granite ridge similar to that described around the flank of the Barton arch so that at least a portion of the so-called "chat" and in some instances an undetermined thickness of the underlying shale may be classed as of sedimentary origin and of Pennsylvanian age. Definite proof of the age should wait on fossil evidence.

C. R. THOMAS: I wish to discuss two major phases of Mr. Barwick's paper: (1) the age of the Welch chert as described by Dr. Moore; and, (2) the question of the introduction of new names into our present literature.

In regard to the age of the Welch chert: Dr. Moore originally described it as a Pennsylvanian chert covering most of the area west of the Nemaha Mountains and consisting of those strata formerly correlated with the Mississippi lime. Mr. Barwick's paper was first read before the Kansas Geological Society on October 1, 1927, and Dr. Moore took a prominent part in the discussion which followed. Shortly after the presentation of this paper, Dr. Moore, following an examination of cuttings from one well on the east flank of the Salina basin, reconsidered his previous correlation and placed the cherty horizon on the east flank of the basin in the Mississippian. He still considers

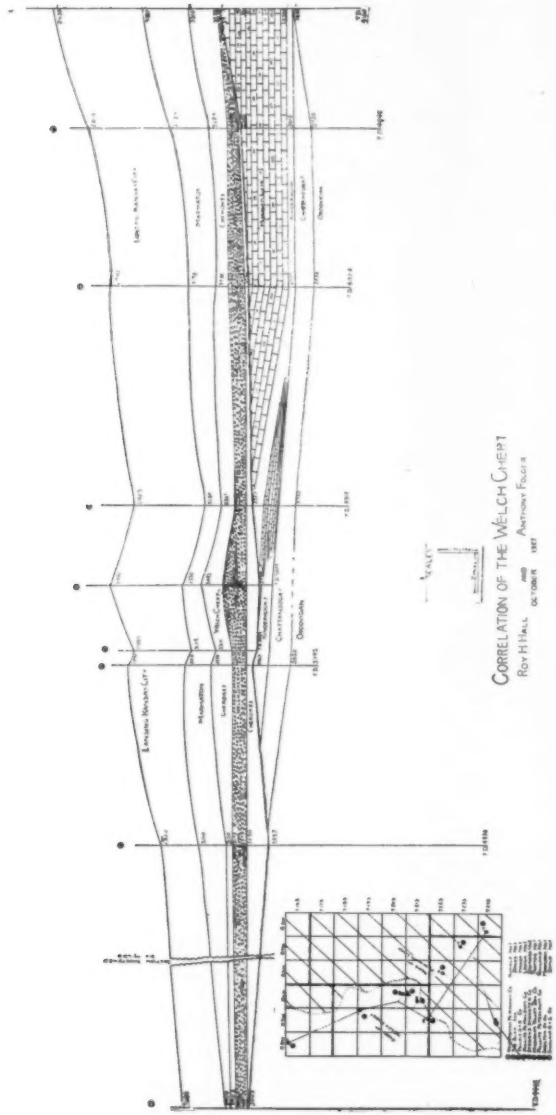
CORRELATION OF THE WELCH CHERT
ROY H. HALL AND ANTHONY FALOTA
OCTOBER 1957

FIG. 4.

his original correlation in the Sheridan well as correct. I have no doubt of his correct identification of the fossils submitted. I object to the correlations given for the Sheridan well on the ground that, since this correlation has never been checked by observation of similar fossils in samples from any other wells in the area, grave doubts may reasonably be cast on the authenticity of the samples submitted to Dr. Moore.

In Mr. Hall's discussion considerable stress is laid upon microscopic examination of well cuttings. This is an important point. Such examinations frequently do alter correlations as made from drillers' logs. Since Mr. Barwick has carefully examined such cuttings as are available in this area the differences between his opinions and Mr. Hall's may be considered as differences of interpretation.

Mr. Hall's Pennsylvanian basal conglomerate in the area of the Barton arch is entirely correct. It seems to me that his correlation of this conglomerate with Dr. Moore's Welch chert in the Salina basin is based on no particular evidence. It is obvious that the major unconformity which extends northwest from the Pennsylvanian coal basin of Arkansas and Oklahoma and becomes progressively greater to the northwest is between the Pennsylvanian and the Mississippian. Consequently his placing the major unconformity in the Salina basin above the basal Pennsylvanian is rather radical in view of accepted facts. Furthermore, the placing of Pennsylvanian strata in contact with pre-Mississippian strata in a trough rather than on an uplift is a somewhat new phenomenon.

In his discussion of Mr. Barwick's paper Dr. Moore has failed to note that Mr. Barwick regards the conglomerate on the Barton arch as being of basal Pennsylvanian age. I believe there is little difference of opinion regarding this point.

In regard to the second phase of my discussion, the introduction of new names for subsurface beds: unlike Oklahoma, Kansas has no convenient mountain area in which the lower Paleozoic beds are exposed. In the area of the Salina basin we have a series of beds which are not found in the southern part of the state and none of which are exposed on the surface for some hundreds of miles. Correlations with exposed beds in adjoining states will not be definitely made for years, if ever. Dr. Moore has made the suggestion that the naming of the subsurface formations should properly follow the custom already established in the naming of new producing horizons, that is, giving them the farm name of the well penetrating such horizons. Mr. Barwick has followed this suggestion.

In view of the above facts it is my opinion, an opinion concurred in by all of the Kansas men with whom I have discussed this question, that Mr. Barwick is eminently justified in the introduction of new names, and that his selection of these names has followed existing precedent in such matters.

ROY H. HALL: No doubt Mr. Barwick does have some different interpretations of well cuttings from those shown on our section. I wish to point out, however, that he has shown the basal Pennsylvanian conglomerate to be equivalent to the top of the Welch chert on his cross-section, C-C. Our differences of opinion on correlation then are confined to the question as to how much of the Welch chert should be called Pennsylvanian and how much

Mississippian, as well as to its origin. We have ascribed a sedimentary origin to the Welch chert due to re-working of residual material by an advancing Pennsylvanian sea. We correlate the entire thickness with the basal Pennsylvanian cherty conglomerate on and down the flanks of the Barton arch. The well-to-well correlation is supported by lithologic evidence. It has been stated before, however, that the age of the Pennsylvanian basal conglomerate is progressively younger west and northwest from the Reno, Rice County, area.

The major unconformity between Pennsylvanian and Mississippian is accepted. So far as we know there is no disagreement with the facts. It is evident that Mr. Thomas has misinterpreted our section. We show the major unconformity to be between the two previously mentioned periods and not up in the Pennsylvanian as Mr. Thomas has interpreted. This unconformity is shown progressing downward in the stratigraphic section westward and northwestward toward the structural feature termed the Barton arch. We think that post-Mississippian pre-Pennsylvanian erosion removed the Mississippian and some of the pre-Mississippian rocks from the crest and from well down the flanks of this arch. A shallow topographic—not structural—basin was developed in the area where Mississippian and pre-Mississippian shales were exposed to the agencies of weathering. We think that the Pennsylvanian sea advancing up this topographic trough, re-worked whatever material was at hand—shales in this instance—and therefore we have shown a small thickness of re-worked shale under the cherty zone as being of Pennsylvanian age. Note that this shale is mostly confined to the area of pre-Pennsylvanian shale outcrop.

Mr. Thomas objects to the placing of Pennsylvanian strata in contact with pre-Mississippian rocks in a trough, describing it as a new phenomenon. We have shown Pennsylvanian rocks overlapping the planed-off beds of Mississippian and pre-Mississippian rocks on the flanks of the Barton arch. The pre-Pennsylvanian trough he refers to is a topographic feature as we have attempted to show on our section—not a structural feature.

JOHN L. RICH: I have read with much interest the preceding discussions of the origin and correlation of the Welch chert. Application of physiographic principles to the interpretation of the facts presented by the various speakers suggests a picture of conditions at the time of the deposition of this material under which all of the diverse views here presented may be correlated and harmonized.

The problem appears to center about the finding of Pennsylvanian fossils by Moore in cuttings from the Sheridan well (Sec. 21, T. 15 S., R. 6 W.) in a shale below the Welch chert. Barwick and Thomas are inclined to think there must have been some mistake and that the fossils could not have come from that position.

Before attempting to draw my picture of the possible physiographic conditions attending the formation of the Welch chert, I would call attention to features recently observed in northern Marion and southern Dickinson counties. In that locality the so-called "chat" of the drillers (presumably the local representative of the Welch chert) seems clearly to lie on or to be the eroded top of the "Mississippi lime." Part of it, at the top, is certainly

more or less re-worked, as is evidenced by the pebbly character of some of the material and the presence of chert pebbles in the shale immediately above. Below the re-worked material appears to be a gradation through residual chert, as described by Barwick, to unaltered cherty limestone, or "Mississippi lime." This cherty zone at the top of the "Mississippi lime" here marks the Mississippian-Pennsylvanian unconformity. Abrupt variations in the thickness of the remaining "Mississippi lime" and other evidences indicate considerable relief in the pre-Pennsylvanian surface.

In this locality the picture at the time of the advance of the Pennsylvanian sea is that of a low, hilly land, deeply mantled with residual chert grading downward into unaltered "Mississippi lime."

Along the east flank of the Barton arch, Hall has pictured a lowland occupying what was then the outcrop belt of the Engle and Skelton shales, bordered on the west by a low upland of Ordovician limestones, and on the east by a low, rolling upland underlain by the Mississippian cherty limestones.

Physiographically, Hall's picture appears true. Only the most extreme and improbable degree of peneplanation would have eliminated these features. On the eastern border of this lowland would have been a more or less pronounced scarp formed by the outcrop of the eastward-dipping Mississippian limestones. This scarp would have marked the boundary between a shale lowland and a gently rolling upland plain, mantled thickly with residual chert grading downward into cherty limestone. A modern analogue is the shale lowland east of the "Flint Hills" scarp (Wreford-Florence) as compared with the chert-floored uplands west of the scarp.

Such is the picture of the landscape at the beginning of Pennsylvanian deposition (Fig. 5).

What would happen if such a landscape were gradually invaded by the sea? As Hall has shown, the shale lowland would first be submerged. If the submergence were slow enough to have permitted filling as submergence progressed, this embayment between the bordering uplands on either side would have become filled with fine materials derived, in part, from a re-working of its floor and in part from streams and material carried in by tides and other agencies. Under the conditions pictured, comparatively little coarse material would have been carried in from the bordering chert-covered uplands because (1) being underlain by limestone, much of their drainage would have been subterranean, (2) the residual chert would have formed an effective protective mantle, and (3) the gradual submergence of the region would have decreased the gradient of the streams, causing them to drop any coarse material they might be carrying in the drowned valleys within the upland.

At the time when the submergence had completely drowned and filled the original shale lowland embayment and the chert-mantled uplands began to be submerged, a new set of forces would have come into action. The waves would have gained access to the residual chert of the upland plain, and totally different deposits would have been formed. As submergence proceeded, and more and more of the upland was brought into the zone of wave action and the waves became more powerful on account of the greater area submerged and their greater sweep, a large amount of loose, cherty material would have been freely available to them and would have been re-worked and spread

widely not only over the upland, but also over the site of the former shale lowland, where exceptionally thick masses of the re-worked chert might have accumulated due to possible lack of complete filling of this area and to possible settling of the earlier filling of mud.

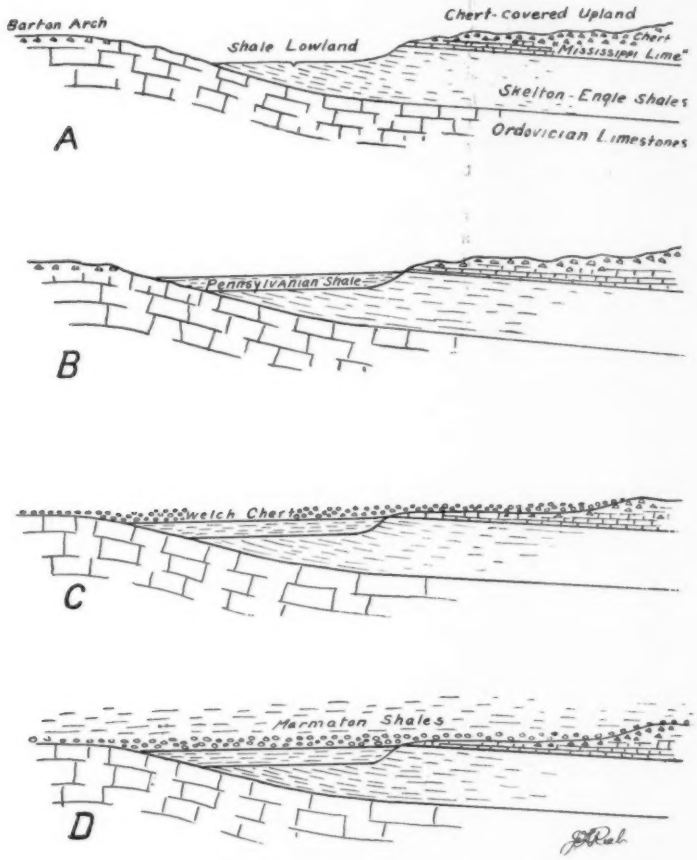

FIG. 5.—Diagrammatic sketches illustrating deposition of Welch chert (vertical scale highly exaggerated); A, pre-Pennsylvanian topography; B, invasion of shale lowland by Pennsylvanian sea, silting up with fine sediments; C, later stage of marine invasion: chert-covered uplands exposed to waves, chert gravels widely distributed by waves; D, continued submergence: chert residues buried, shales deposited over entire area.

In this manner a wide spreading of re-worked cherty material could be accomplished without renewed uplift, such as was postulated by Moore.

If such were the history of the early Pennsylvanian marine encroachment over this area, it is not surprising that the Sheridan well, which appears to have been located in the area of the pre-Pennsylvanian shale lowland belt, should have encountered fossiliferous Pennsylvanian shales (representing the early filling of the lowland by the encroaching sea) beneath the Welch chert which here represents the re-worked cherty material spread out by the waves after submergence had brought the "Mississippi lime" upland down within their reach.

Under this theory all of the facts which have caused the rather widely differing explanations of the origin and correlation of the Welch chert seem to fit together into a picture which harmonizes the observation of Moore that the Welch chert (in places at least) is secondarily re-worked material and that Pennsylvanian fossils are found beneath the Welch chert in at least one locality, with the theory of Barwick that the chert (in some places, at least) is due to weathering in place and secondary silicification of the "Mississippi lime," and with the difficulty encountered by Hall in not having his Pennsylvanian basal conglomerate everywhere at the unconformity at the base of the Pennsylvanian.

If the picture sketched above represents the true condition, the cherty zone which has been called Welch chert is in one place a bed of re-worked chert interstratified with Pennsylvanian shales; in another it is a basal conglomerate of the Pennsylvanian; and in still another it is, in its top few feet, a basal conglomerate of the Pennsylvanian, and, below that, a residual chert formed by decay and alteration in place of the "Mississippi lime;" and, nevertheless, it is one connected lithologic unit representing various phases of the re-working of the residual cherts of the pre-Pennsylvanian cherty limestones by the advancing Pennsylvanian sea.

ANTHONY FOLGER: Most of the discussion of Mr. Barwick's paper has centered around the relationship of the Welch chert to the "Mississippi lime." Little has been said concerning his correlations below the base of the "Mississippi lime."

Mr. Barwick has subdivided the strata below the base of the "Mississippi lime" and above the St. Peter sandstone into four units, namely, Skelton shales (basal Mississippian), Younkin formation (Siluro-Devonian), Engle shale (Ordovician), and Urschel lime (Ordovician). All of these are new names. Mr. Thomas has stated in his discussion that all of the Kansas men with whom he has discussed the matter are in agreement that Barwick is eminently justified in the introduction of these names. But there are others of us in Kansas that are not in entire agreement.

Some argue that Mr. Barwick should not depart from the use of outcrop terminology, both because so great a thickness of strata is involved in each unit and also because the literature is already so encumbered with superfluous names. Personally, I subscribe heartily to this premise. But I further believe that subsurface work has advanced today to such a stage of refinement that the introduction of new stratigraphic handles, other than outcrop terminology, is sometimes both necessary and convenient; the more es-

pecially when it happens that subsurface deposits exist which are so radically different in character from surface deposits of approximately the same age as to render correlation between them difficult and uncertain.

Relative to Mr. Barwick's terminology I desire to subscribe to his usage of Skelton and Younkin, and to object to the usage of Engle and Urschel. My reasons are as follows:

The Skelton shale of Barwick includes the Kinderhook and Chattanooga. Southward from Marion County both the Kinderhook and Chattanooga are easily recognizable units in well logs and the usefulness of the term Skelton ceases. Northward from Marion County the Chattanooga completely disappears, and a thick characteristic body of shale appears in the section (totally different from anything present in southern Kansas) which seems to be correctly placed as of Kinderhookian age. Barwick has pointed out that the outcropping Kinderhookian section of the Mississippi River valley has been so intricately subdivided that exact correlation of this shale unit with the type section cannot be accomplished at present. To simply apply the name Kinderhook to this shale unit would perhaps be satisfactory, but it lacks preciseness. I therefore can see no objection to the use of Skelton shales in northeastern Kansas.

The Younkin formation Barwick defines as of Siluro-Devonian age. In Iowa, the Siluro-Devonian is divided into the

DEVONIAN
Cedar Valley limestone
Wapsipinicon formation

SILURIAN
Gower dolomite
Hopkinton dolomite
Edgewood limestone

Following Ulrich, it seems certain that not all of the Siluro-Devonian is represented in the Younkin formation. On the other hand there can be no doubt that a very considerable thickness of Siluro-Devonian extends into northeastern and north-central Kansas, both east and west of the granite ridge. In fact it appears that one of the areas in Kansas in which these deposits are the thickest lies west of the granite ridge in Clay and Riley counties. Here then is a unit of limestone, attaining in places a thickness greater than 400 feet in northeastern Kansas and apparently not representing all of Siluro-Devonian time, which is greatly in need of a stratigraphic handle other than existing outcrop names. The choice of Younkin appears satisfactory.

Mr. Barwick correlates the Engle shales with the Sylvan of Oklahoma and Maquoketa of Iowa. Apparently his only justification for the use of a new term is that there is some disagreement as to the exact relationship of the Sylvan to the Maquoketa. However, since the Sylvan-Maquoketa correlation is one quite generally accepted there seems no need for the introduction of the term Engle. Would it not be better to use Maquoketa for the general northern Kansas area and Sylvan for the southern Kansas area?

The Urschel lime of Barwick is stated to be approximately equivalent to the Viola of Oklahoma, the Kimmswick-Plattin of Missouri, and the Galena-

Platteville of Iowa. Here is a case where the Black River and Trenton groups of the Ordovician have not been intricately subdivided at the outcrop. Furthermore there are some wells in extreme northeastern Kansas and southern Nebraska wherein a shale unit appears in about the middle of Barwick's Urschel lime which possibly corresponds to the Decorah shale. Should this prove correct and if Urschel is retained, one would have to designate the strata as upper Urschel, Decorah shale, and lower Urschel—a nomenclature which would be quite inconvenient. It would seem far better to continue using Viola or Kimmswick-Plattin, instead of the new term Urschel, even though the exact correlation is yet uncertain. This would also permit the using of Galena, Decorah, and Platteville in those areas where a shale unit appears in the middle of this limestone unit. Inasmuch as Urschel includes but two well known formations, the Kimmswick and the Plattin, it would be more helpful to use Kimmswick-Plattin than a term which does not call to one's mind any particular horizon in the stratigraphic column.

J. S. BARWICK: In answer to Mr. Folger's criticism of the use of the terms "Engle" and "Urschel," I can only reiterate my statement that it seems preferable to use new names rather than outcrop names which further information may prove to be incorrect. For instance, Mr. Folger states that the Urschel lime should be called Kimmswick-Plattin; but in case the Decorah shale is found he suggests that we could then use the names, Galena, Decorah, and Platteville. As a matter of fact, the use of either of these sets of names is unjustified at the present time.

GEOLOGICAL NOTES

THE MISSOURI-IOWA FIELD CONFERENCE

The Kansas Geological Society sponsored recently a Missouri-Iowa field conference, which assembled at Columbia, Missouri, on Monday morning, September 5, and closed at Decorah, Iowa, Saturday night, September 10. In Missouri the conference was conducted by E. B. Branson, head of the department of geology, University of Missouri, assisted by Maurice G. Mehl, associate professor of geology, and by three of their graduate students, Carl Branson, A. K. Miller, and L. S. Baumgartner. The Iowa leadership was directed by George F. Kay, head of the department of geology and dean of the College of Arts and Sciences at the University of Iowa, as well as state geologist, assisted by A. O. Thomas, professor of paleontology, James H. Lees, assistant state geologist, and George Marshall Kay, instructor of geology at Columbia University. Attendant in an advisory capacity were Josiah Bridge, assistant professor of geology, Missouri School of Mines; Rollin T. Chamberlin, professor of geology, University of Chicago; G. E. Condra, state geologist of Nebraska; Carl O. Dunbar, professor of paleontology, Yale University; Charles N. Gould, state geologist of Oklahoma, and Raymond C. Moore, state geologist of Kansas. The total attendance was 41.

The salient purpose of this conference was to examine at the outcrop those Paleozoic formations in eastern Missouri and Iowa, emphasizing the Ordovician, which have been tentatively identified from the study of drill cuttings of numerous deep borings in north-central and northeastern Kansas. Unsuccessful attempts have been made in the past to correlate the Ordovician strata of these wells with the Ordovician of Oklahoma. For some time, however, it has been apparent that in a general way this post-Simpson sequence can be more easily associated with the Ordovician of Missouri and Iowa. In eastern Missouri and Iowa the formational nomenclature of the Paleozoic has been worked out in considerable detail. It is quite unlikely that all of these formations extend underground into Kansas as unchanged lithologic units. It was thus essential to study the characteristics of the formations at their outcrops, and to attempt preliminary correlation

between them and the subsurface Paleozoic deposits of northeastern Kansas.

A valuable result forthcoming from this conference will be the examination of the collections made by micro-paleontologists of the lithology and fauna of each formation studied. Great quantities of these samples were taken back to the laboratories of the major companies in Tulsa, Wichita, and Ponca City. These collections will form the basis for comparison between the lithology and fauna at the outcrop and the cuttings obtained from deep borings in northeastern and north-central Kansas. Undoubtedly this will permit a more accurate determination of cuttings from these wells in the future.

The conference was an even greater success than had been anticipated by those who sponsored it. An expression of appreciation is due Dr. Branson, and to those who coöperated with him, in arranging the trip so that the party could view a complete Paleozoic column north of Missouri River. The carefulness of preparation and the remarkable presentation of the geology of the Iowa portion of the conference will long be remembered. Words cannot express our gratitude and our feeling of regard for Dr. Kay and his able assistants, Dr. Thomas, Dr. Lees, and Marshall Kay. Excellently prepared photostatic copies of stratigraphic sections (the result of much labor on the part of Marshall Kay) were presented to the members at the beginning of each day. The preparation of these stratigraphic sections and the lectures which were delivered at each locality were a distinct contribution to science.

One of the most instructive and enjoyable features of the conference was the evening program of discussions of each day's field observations, led by authorities on the geology involved.

THE CONFERENCE IN MISSOURI

The stratigraphic column examined in Missouri included the following formations:

MISSISSIPPIAN

Burlington limestone
Kinderhook formation
Hannibal shales
Louisiana limestone
Grassy Creek shales-Chouteau limestone
Sylamore sandstone

DEVONIAN
- Snyder Creek shales
- Callaway limestone
- Mineola limestone
- Cooper limestone

SILURIAN
- Alexandrian group
  - Sexton Creek limestone
  - Edgewood formation
    - Noix oölite
    - Cyrene limestone

ORDOVICIAN
- Cincinnatian group
  - Maquoketa shale
- Mohawkian group
  - Kimmswick limestone
  - Plattin limestone
- Chazyan group
  - Joaquin limestone
  - St. Peter sandstone
- Beekmantown group
  - Jefferson City

Brief mention will be made of the localities visited and the formations observed:

Locality 1.—On the north bank of Missouri River, near Providence, at the confluence of Little Bonne Femme Creek and Missouri River, an opportunity was afforded to study the Jefferson City formation, the St. Peter sandstone, the Callaway limestone, the Sylamore sandstone, and the Chouteau and Burlington limestones. Of interest to everyone at this locality was the unconformity between the Cooper and the Jefferson City as well as between the Cooper and the Callaway.

Locality 2.—At New Bloomfield observations were made of the Snyder Creek shales resting conformably on the Callaway limestone which is underlain in turn by the Jefferson City formation.

Locality 3.—In the vicinity of Mineola the sequence observed included the Jefferson City, St. Peter, Joaquin, Plattin, Mineola, Callaway, Sylamore, and Burlington, with a complete absence of Chouteau. The Plattin limestone at Mineola contains a fauna similar to that found in the Decorah of Iowa and, according to Marshall Kay, the Spechts Ferry shale, which is the lowest member of the Decorah,

is equivalent to the upper part of the Plattin limestone in Missouri and is, therefore, of Black River age.

Locality 4.—About 8 miles northwest of Winfield a study was made of the formations present along the Cap-Au-Gres fault. On the upthrow side a section is exposed from the St. Louis limestone down to the Jefferson City. On the downthrow side Maquoketa shales are in contaact with St. Peter sandstone. The maximum displacement is about 300 feet and the fault passes northwestward into a fold.

Locality 5.—Some of the best exposures seen in northeastern Missouri are in the high bluffs at Louisiana on the west side of Mississippi River immediately south of the town. The lowest beds are Maquoketa shales (Ordovician) overlain by the Edgewood formation (Silurian) which is here divided into the Noix oölite and Cyrene limestone. This is followed by Grassy Creek shales, Louisiana limestone, Hannibal shales, and Burlington limestone. An excellent fauna has been preserved in some of these beds and considerable time was spent in collecting. So characteristic are these exposures that it might be well to include some detailed observations on their lithology.

The Maquoketa shale (called Hudson River shale in the older reports) is a greenish-gray shale with interstratified thin beds of resistant flaggy limestone. Many of the shales are very calcareous and this calcareous content increases northward. The Noix oölite is a gray granular limestone with masses of white, extremely distinctive oölites scattered through it. It is equivalent to the Chimney Hill limestone of the Arbuckle Mountain section of Oklahoma. The Cyrene limestone (sometimes called the "Brown lime") is a brown earthy magnesian limestone, weathering into thin beds, and distinguished from the overlying Bowling Green dolomite by its earthy appearance and by the large number of its fossils.

Above the Noix oölite at Louisiana, are the blue and black fissile Grassy Creek shales of Kinderhook age. This black shale is devoid of fossils, but a very thin sandstone at its base contains many fish teeth. Following this is the Louisiana limestone, a characteristic coarse-grained, blue, thin-bedded, and lithographic limestone. It has a distinctive conchoidal fracture, and contains a large fauna in which brachiopods predominate. The overlying Hannibal shale is an extremely characteristic indigo-blue shale with a sandy horizon at the top called the "Vermicular sandstone." This shale horizon is one of the most persistent and widespread members of the Kinderhook group. The shale yields a small fauna, but the overlying Vermicular sandstone is

filled with worm borings, as well as brachiopods, gastropods, and lamellibranchs.

The highest formation exposed at Louisiana is the Burlington limestone, which at this locality may be conveniently divided into an upper and a lower horizon.

Locality 6.—In the vicinity of New London outcrops of the Plattin-Kimmswick group were examined. Considerable time was spent in collecting the plentiful and characteristic Kimmswick fossil, *Receptaculities oweni*. Lithologically, the Kimmswick is gray, coarsely granular limestone, easily distinguishable from the dense lithographic limestone of the Plattin. Its weathering is distinctive in that the limestone is perforated with large and small holes due to the weathering-out of soft spots in the lime. Another feature of the Kimmswick is the poor preservation of its fossils, which are as a rule only casts. The uppermost few feet of Kimmswick beds have been divided into three zones, from top to bottom, respectively: *Orthoceratites* zone (in contact with the Maquoketa shales above), *Receptaculites* and *Murchisonia* zone, and *Strophomenoid* zone.

Locality 7.—Near Hannibal a magnificent exposure was studied of the Hannibal shales, Louisiana limestone, and Grassy Creek shales. It is of interest to point out a feature which is well exemplified at this locality, namely, the progressive thickening northward of all the Mississippian formations.

After the section was examined at Hannibal the Missouri leaders left the party and Dr. Moore led the conference from Hannibal north to Keokuk and Burlington, Iowa, by way of the highway along the east side of Mississippi River in Illinois. At Burlington the Iowa leaders joined the conference.

THE CONFERENCE IN IOWA

The stratigraphic column studied in Iowa included the following formations:

MISSISSIPPIAN
- Meramac group
  - St. Genevieve
  - St. Louis
  - Spergen
  - Warsaw
- Osage group
  - Keokuk
  - Burlington
- Kinderhook group

UPPER DEVONIAN
- Senecan group
  - Cedar Valley
  - Wapsipinicon formation
    - Upper Davenport limestone
    - Lower Davenport limestone

SILURIAN
- Niagaran group
  - Gower dolomite
    - Alamosa
    - Eclir
  - Hopkinton dolomite
- Alexandrian group
  - Edgewood limestone

ORDOVICIAN
- Cincinnatian group
  - Maquoketa shales
    - Brainard shale
    - Fort Atkinson limestone
    - Clermont shale
    - Elgin shale
- Mohawkian group
  - Galena limestone (Prosser lime of northeast Iowa)
  - Decorah shale
    - Ion shale
    - Guttenberg limestone
    - Spechts Ferry shale
  - Platteville limestone (McGregor lime of northeast Iowa)
- Canadian group
  - Chazyan group
    - Glenwood shale
    - St. Peter sandstone
- Beekmantown group
  - Prairie Du Chien formation
    - Shakopee dolomite
    - New Richmond sandstone
    - Oneota dolomite

CAMBRIAN
- St. Croixan group
  - Jordan sandstone
  - St. Lawrence limestone
  - Franconia sandstone

HURONIAN (ALGONKIAN)
- Sioux quartzite

Of these formations the following were not seen: the St. Genevieve and the St. Louis (Mississippian), the Gower dolomite and Edgewood limestone (Silurian), and the Sioux quartzite.

A resume of the Iowa localities visited during the conference follows:

Locality 1.—At Keokuk, a limestone quarry, together with high cliffs across the road, afford excellent exposures of Warsaw shales and Keokuk limestone. The strata in the cliffs and in the quarry are rich in fossils and much time was spent in collecting. The Keokuk limestone is underlain by Burlington limestone, and the great Keokuk dam, across Mississippi River at Keokuk, is located at the shoal formed by Burlington limestone. The Warsaw shales are composed of arenaceous and calcareous shale, buff sandy and magnesian limestone and geode beds. The Keokuk limestone is a coarse-grained, blue, crinoidal limestone with much nodular chert.

Locality 2.—Some distance southeast of Burlington, at Prospect Hill, an examination was made of the Kinderhook group, which is here divided into six members, each forming a complete lithologic unit. These six horizons in sequence from top to bottom, are: buff magnesian limestone, white oölitic limestone, yellow fossiliferous sandstone, argillaceous limestone, yellow clayey sandstone, and blue argillaceous shale. Zone 4 contains a prolific fauna of lamellibranchs, gastropods, and peculiar brachiopods and may be equivalent to the Vermicular sandstone of Missouri. Zone 1 is the most important horizon economically and is used in the manufacture of brick and clay goods.

Locality 3.—Some miles southwest of Davenport the Cedar Valley limestone and Wapsipinicon formation were studied at the Linwood quarry. An excellent collection of fossils was obtained from the Cedar Valley limestone and attention was called to the similarity of the fauna of the Cedar Valley limestone of Iowa and the Callaway limestone of Missouri. At this locality the Wapsipinicon is divided into two members, the upper and the lower Davenport. These two units are very distinct lithologically, and in addition the upper Davenport is fossiliferous whereas the lower Davenport is devoid of fossils and is highly brecciated.

Locality 4.—At Hurtsville, in one of the quarries, a magnificent exposure may be seen of Hopkington dolomite of Niagaran age. The Hopkington is a heavy-bedded buff dolomite somewhat resembling the Galena. The individual lime beds are commonly lenticular. In places the formation is siliceous. The characteristic fossil at this locality is *Pentamerus oblongus*. This *Pentamerus oblongus* zone forms a definite

lithologic unit overlain by a *Cerionites* zone and underlain by a *Syringopora lenella* zone. Above the Hopkington dolomite, but not exposed at this locality, is the Gower dolomite, which is divided into two members, the Alamosa at the top and the Eclir at the bottom.

Locality 5.—DuBuque, Iowa. Two localities were examined at DuBuque: one at St. Paul's College and the other at the Eagle Point Lime Works. At St. Paul's College the only exposures are the very basal part of the Maquoketa and the upper part of the Galena, which is extremely thin-bedded. At the Eagle Point Lime Works the vertical quarry walls expose about 200 feet of Galena dolomite. Here, the Galena is heavy-bedded, crystalline, and completely dolomitized. The bedding planes have been almost obliterated. Chert-bearing beds occupy a definite horizon, 50 feet thick, in the middle of the quarry walls. At the very base of this exposure there is a few feet of green Decorah shale carrying a typical Decorah fauna.

Although the Galena is completely dolomitized at DuBuque, the degree of dolomitization decreases progressively northward. In extreme northern Iowa the formation has changed to a limestone and in southern Minnesota to a shale.

Locality 6.—Patch Grove, Wisconsin. Heavy rains prevented our continuing northward in Iowa from DuBuque to McGregor and it was necessary to detour across Mississippi River at DuBuque into Wisconsin and again enter Iowa by way of the ferry between Prairie Du Chien and McGregor. At Patch Grove, Wisconsin, the Decorah shales are exposed. They contain a most prolific fauna, of which large collections were made. Marshall Kay has divided the Decorah shales into three members, from top to bottom, respectively, as follows: Ion shales and limestone, Guttenberg limestone, and Spechts Ferry shale.

Patch Grove is the lype locality of the Spechts Ferry shale. The Guttenberg limestone contains the "oil rock" and the Spechts Ferry shale contains the "glass rock." The Ion and the Guttenberg are of Trenton age, with the Ion equivalent to the Rockland, and carrying a characteristic Trenton fauna. The Spechts Ferry is of Black River age, and, according to Marshall Kay, is correlated with the upper 3 feet of the Watertown formation of New York. It is his belief that it is the Spechts Ferry fauna which is being found in the Kansas wells. In Wisconsin and Illinois the upper and middle members of the Decorah are at times included in the lower part of the Galena, and the lower member of the Decorah is included in the upper part of the Platteville. Attention is called to the fact that the Ion shale at Patch Grove is both

a dolomite and a limestone, whereas at DuBuque it is entirely a dolomite and in Minnesota it is entirely a shale.

Two remarkable features of the Decorah are its constant thickness throughout vast areas and its inconsistent sedimentation. It has a uniform thickness of about 40 feet. While Decorah lithology is by no means as inconsistent as Maquoketa lithology, nevertheless it presents a remarkable change from north to south. In Missouri the correlative of the Decorah is the Aubyn chert.

Locality 7 (*Marquette*).—About two miles north of McGregor on the west bank of Mississippi River is the station of Marquette. Here, the Jordan sandstone of Cambrian age stands out in prominent bluffs. It is a yellow, very soft, incoherent and unstratified sandstone, highly cross-bedded, and of many colors.

Locality 8.—In the vicinity of McGregor a complete section was observed beginning with the Jordan sandstone, followed by the Prairie Du Chien formation and St. Peter sandstone, which in turn is followed by the Glenwood shales, the Platteville, Decorah, and Galena. Special attention was paid to the Glenwood shale and its resemblance to, and probable correlation with, the Tyner of Oklahoma were mentioned. It is an 8-foot horizon of extremely green shale resting on the St. Peter. At this locality the unconformable relationship of the St. Peter sandstone to all the subjacent formations is well exemplified in that it may rest on anything from Shakopee down to Oneota, inclusive.

Locality 9 (*Waukon*).—On the main highway not far from Waukon considerable time was spent in collecting fossils from the Ion shale member of the Decorah. As here exposed it is predominantly gray and green shale. The fauna is mostly of bryozoans and brachiopods.

Locality 10 (*Lansing*).—One of the most complete sections of lower Ordovician and Cambrian sediments examined in Iowa was observed in the vicinity of Lansing. The lowest rocks exposed are the Franconia sandstone of which only the top 125 feet is represented. The Franconia is a soft incoherent and well-stratified sandstone, generally of gray or brown color, but also containing narrow bands of green and yellow sand. It is locally cross-bedded. Above the Franconia is the St. Lawrence limestone, which is a dull-colored limestone, both massive and laminated, containing a trilobite fauna. Resting on the St. Lawrence is the Jordan sandstone. These three formations form the St. Croixan group of the Cambrian.

The St. Croixan is overlain by the Beekmantown, represented by the Prairie Du Chien formation. The Oneota dolomite contains a few

beds of massive dolomite; the remainder are composed of magnesian and crystalline limestone. The New Richmond sandstone, which forms the middle member, presents thin arenaceous beds of sandstone with interstratified layers of dolomite and is probably equivalent to the Roubidoux sandstone of Missouri. The Shakopee dolomite is composed entirely of gray heavy-bedded dolomite, and is at least in part equivalent to the Jefferson City of Missouri.

The St. Peter sandstone and the Glenwood shale of Chazyan age overlie the Prairie Du Chien formation. The St. Peter is an incoherent and poorly stratified sandstone composed of water-worn quartz grains. Although brown is the predominating color it is more generally characterized by variations of white, red, and yellow, depending upon the amounts of ferric oxide in different degrees of hydration. One of the chief differences between the St. Peter and the St. Croixan sandstones is the higher coloration of the St. Peter. Overlying the St. Peter is about 8 feet of bright green Glenwood shale.

Locality 11 (*Decorah*).—The type section shale is at Decorah. Unfortunately, the type section is now in an extremely poor state of preservation and for this reason was not visited. However, an excellent exposure was examined a short distance northwest of Decorah where the Spechts Ferry, Guttenberg, and Ion members are all composed of green shale. The Spechts Ferry at this point is exceedingly fossiliferous.

Locality 12 (*Fort Atkinson and Clermont*).—In the vicinity of Ft. Atkinson and Clermont, in Fayette County, a study was made of the Maquoketa. The Maquoketa is one of the most changeable formations in the Paleozoic of Iowa. At the type section, along Little Maquoketa River in DuBuque County, it is argillaceous throughout its entire 200 feet of thickness. There, it is divided into two horizons, an upper horizon of 150 feet of bluish-green plastic clay shales with a few hard fossiliferous beds at the top, underlain by 50 feet of bluish-green fissile shale with a considerable number of earthy non-laminated beds containing an *Orthoceras* fauna. The argillaceous character of the Maquoketa changes northwestward until finally in the extreme northern part of Iowa the Maquoketa is represented by only limestones and dolomites.

In the vicinity of Ft. Atkinson and Clermont the Maquoketa has been divided into four members from top to bottom as follows: Brainard shales, Ft. Atkinson limestone, Clermont shales, and Elgin shale. The Brainard is plastic bluish shale about 125 feet thick, with a few feet of thin limestone bands at the top which contain the only fossils in this member. The shales are characterized by crystals of selenite. The

Ft. Atkinson limestone is cherty and in places considerably magnesian. The limes are well bedded and contain much nodular chert. Many parts of the Ft. Atkinson are completely dolomitized. It ranges in thickness from 40 to 60 feet. The Clermont shales are bluish fine-grained plastic clay shales, widely used in the manufacture of brick. The Elgin is divided into two zones: an upper zone composed of calcareous shales containing a beautiful trilobite fauna and a lower zone of interstratified shales and limestones containing an *Isolelus* and *Asaphus* fauna.

The correlation of the Maquoketa shale with the Oklahoma section was a much-discussed point. According to the consensus of opinion the Maquoketa is equivalent to the Sylvan shale of Oklahoma.

ANTHONY FOLGER

WICHITA, KANSAS

DISCUSSION

GEOLOGY OF GLENN POOL OF OKLAHOMA

Wilson's paper on Glenn pool[1] is extremely interesting and suggestive. It is a brief, but clear, exposition of the geology of the pool, together with a discussion of the scientific problems suggested by the relation of oil accumulation to structure and other geological conditions. If similar papers could be prepared for all oil pools, the gain to the science of petroleum geology would be very great.

In the belief that full discussion of the principles of petroleum geology as applied to specific examples such as those presented in Wilson's paper is highly desirable, and that the presentation of possible interpretations differing from those suggested may aid in clarifying the problems and in the search for new pertinent data, the following discussion is offered.

On p. 1062, in discussing the low gravity of the oil from the Mounds sand, Wilson writes: "It may be noticed by referring to Figure 1 that an opportunity was problably afforded for the lighter oil constituents to escape from the Mounds during the period of erosion represented by the unconformity at the top of the sand." This interpretation implies that the oil in the Mounds sand accumulated prior to the erosion represented by the unconformity at its top. If so, this body of oil must have lain essentially at the surface of the ground during the period of erosion represented by the unconformity. This seems very unlikely because such exposure should either have permitted the escape of the oil or have altered it to a tarry residue. Moreover, the Mounds oil is now found on the tops of small closed structures and these structures are reflected reasonably closely in the Bartlesville sand above, as is shown in Figure 2. This indicates that the folding which formed these domes is post-Bartlesville. If these domes in the Ordovician rocks had been present, causing oil accumulation prior to the period of erosion, their higher parts, which now contain the Mounds oil, should have been planed off beneath the unconformity.

Two alternative explanations of the heavy grade of the oil in the Mounds sand beneath the unconformity may be suggested. One is that during the period of erosion represented by the unconformity the rocks then at the surface (Mounds sand, etc.) became oxidized and that after these rocks had been buried and the Mounds sand saturated with oil, these oxidized rocks were reduced by the oil, which was made heavier in the process. A second suggestion is that the oil may have been oxidized by sulphate waters in the present physiographic cycle. It would be interesting to know the nature of the water associated with this oil. Should the water carry considerable sulphate, one

[1]W. B. Wilson, "Geology of Glenn Pool of Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 1055-65.

would be justified in seeking an explanation of the low grade of the oil in the effect of the artesian circulation of westward-moving meteoric water. Such a circulation would carry sulphate contamination for long distances in a freely porous sand, while a lenticular sand like the Bartlesville might be unaffected.

In looking to other than a strictly local source for the oil of prolific pools like the Glenn, I am fully in accord with Wilson, but lateral migration and accumulation from a considerable area does not, it seems to me, necessarily imply direct up-dip migration due to buoyancy. A similar concentration of oil on the up-dip side of a long and relatively wide sand lens might be effected by a movement of rock fluids containing oil lengthwise of the sand body, in this case, for example, northwestward. In such movement the tendency of the oil to work its way up the dip as it is borne along would always be present and the total up-dip movement of the oil might well be considerably greater than if the rock fluids were stationary.

Another possible means by which oil might have been concentrated in its present position is by its original migration to the district in a porous lower sand, such as the Mounds, and its leakage upward into the Bartlesville through fractures associated with one or more of the rather sharply folded structures revealed by the sub-surface map of the "Wilcox" (Fig. 3). The present heavier grade of the Mounds oil does not preclude this explanation because it may well be a relatively recent effect of circulating artesian waters. If the oil had originally been widely disseminated through the Bartlesville sand body west and southwest of Glenn pool and had been concentrated on the up-dip margin of this sand body, either, as Wilson suggests, by up-dip migration due to buoyancy or by segregation from rock fluids moving lengthwise of the sand body, as here suggested, it would seem as if all local structures, at least those having "closure," "in the townships to the south and west for many miles," should have caused accumulation of some of this migrating oil. Such reasoning appears to favor the hypothesis of accumulation in the Bartlesville by leakage from below, as does also the seeming lack of oil on the up-dip side of the sand body in other apparently favorable traps along its edge, for example, in Sec. 15 and W. ½ Sec. 14, T. 18 N., R. 11 E. (Fig. 5).

In the last paragraph, p. 1065, in discussing the possibility of up-dip migration due to buoyancy, Wilson writes: "Migration may never have taken place at a rate that could be detected in a few days or weeks in laboratory experiments;" also, "Due to differences of gravity there is a constant pressure tending to drive oil up the dip of inclined strata when it is associated with water." Admittedly, geologic time is ample for very slow movement to accomplish large results, but what of static friction? A smooth block on a slightly inclined plane will remain stationary indefinitely. Only when the inclination of the plane reaches a certain minimum does movement start. The analogy applies in the case of a bubble of oil in water between sand grains or even on the under side of a smooth inclined plane. Until a certain critical force is exerted, no movement occurs. *Time is not a factor.* A variety of conditions may make possible slow up-dip migration of oil on account of buoyancy, but the effect of static friction and its bearing on the time element should not be overlooked.

In the above discussion a number of additional questions have been raised about the migration and accumulation of oil in Glenn pool in relation to the geological conditions of the pool. Perhaps other readers may be able to contribute data bearing on some of these problems.

JOHN L. RICH

OTTAWA, KANSAS
December 10, 1927

REVIEWS AND NEW PUBLICATIONS

The Earth and Its Rhythms. By CHARLES SCHUCHERT and CLARA M. LEVENE. D. Appleton & Co., New York and London, 1927. xvi + 410 pages. Price, $4.20 postpaid.

This book is written to provide for the lay reader a generalized view of geological science and to bring to him "……some sense of the marvels that lie hidden in the rocky framework of this earth of ours, some vision of the 'procession of geographies' that have preceded its present familiar contours, or some clue to the age-old puzzle of the whence and whither of man…." Consistent with its purpose, the book presents little that will be new to the trained geologist. It is excellently illustrated by photographs and pen-and-ink sketches.

The first half of the book covers the general field of physiographic, dynamic, and structural geology, including the topics ordinarily treated in text books under those headings, but it is written in the style of a story, rather than of a text book. Possibly unavoidably, this half of the book is rather disjointed. It is marred in places by inaccuracies seemingly not excusable on the plea of necessity for clear presentation to the non-technical reader.

The second half of the book is a fascinating story of the rise and development of life on the earth; of changing environments; of the diverse forms of life which have come and gone in response to them; and of the evolution of other forms into those that we know today. It is difficult to lay aside this section of the book until it is finished.

JOHN L. RICH

Oil and Gas Resources of Kansas: Anderson County. By HOMER H. CHARLES. *State Geological Survey of Kansas, Bulletin 6,* Part VII, Lawrence, Kansas, 1927. 95 pp., 13 figs., X pl. Price, $0.20.

Charles' report on Anderson County is a notable contribution to knowledge of the shoestring sand bodies of Kansas and of their relation to the accumulation of oil and gas. The report is particularly valuable on account of the large amount of detailed first-hand information which it records and the excellent illustrations which make this information readily available. It is the most comprehensive study of a shoestring area yet printed.

The report begins with the customary description of the rocks exposed and encountered by the drill within the county. This is followed by a section on "Structure" which is of more than ordinary interest because of the discussion of the origin of the structures. Summarizing this section, the author says that "……the abnormal dips……are believed to have been caused chiefly by thickening and thinning of the Pennsylvanian sediments, especially the members of the Lansing formation, and by readjustments in the deep,

competent rocks. Differential settling over the Mississippian floor may be responsible for some of the very gentle dips. The writer recognizes the plausibility of the uneven compaction theory, but has not found sufficient evidence to convince him that the reflection of subsurface features in this district can be traced upward as far as the formations now exposed."

The section on structures is followed by a discussion of the "Accumulation of Oil and Gas" in which special emphasis is given to the effects of the prevailing long, narrow sand trends and to the absence of water in the most important oil-bearing sands. Following this, the principal oil and gas sands and the relation of production to structure in each are briefly discussed. A discussion of the origin of the shoestring sand bodies is illustrated by diagrams, a distribution map, and a plate of cross-sections made from well logs. Three types of sand bodies are distinguished,—bars, shallow water or beach deposits, and channel fillings.

The succeeding section, which forms the bulk of the report, is devoted to descriptions of each of the more important oil and gas fields in which the history of development, structure, sands, relation of oil and gas accumulation to structure, and production records are treated. For most of the fields structure maps, sand maps, and production curves are given.

In a later section of the report are discussions of some of the broader problems of the relations between accumulation and structure in the shoestring sands, gravities of the oils, and absence of water from some of the sands. It appears that in one of the longer channel shoestrings the richest accumulations of oil were found on the high parts of the longitudinal profile of the string, with less productive and poorly saturated sand on the lower points. In another channel string the richest oil accumulation was found in the low of the longitudinal profile, while gas occupied the high. These conditions, together with the gradation into heavy oil on the down-dip ends of two of the strings, are believed to be related to former water levels in the region. The absence of water from certain of the oil sands is a puzzle for which no entirely satisfactory explanation has been offered.

A final section, which will be of much interest to geologists who have occasion to work in Kansas, is entitled "Discovering and Tracing Shoestring Sand Bodies." The use of the principle of differential settling over sand bodies; the reflection, by differential settling, of topographic features in the top of the "Mississippi lime" favorable for the deposition of sands; contouring of key beds close to the producing sand for evidences of settling over the sand; and the search for traces of sand at the producing horizon, with or without oil showings, are discussed and their relative value indicated. Forward projection of the isobathic contours of the channel deposits has proved most effective for short distances.

JOHN L. RICH

Isostasy. By WILLIAM BOWIE. E. P. Dutton and Company, New York, 1927. 275 pp., 39 illus. Price, $5.00; postage, $0.20 extra.

This book is a very thorough review of the development of the theory of isostasy. Isostasy is defined as the science of the equilibrium of the earth's

crust and is considered by Bowie to be a condition of equilibrium, not an active agent.

The earliest known work on this subject was by Herschel and Babbage in the early part of the last century. Airy and Pratt developed the idea as a result of their surveys in India. Dutton published a paper in 1889 in which he concluded that the contraction theory could not account for the major changes in elevation of the earth's crust, and that these changes were caused by erosion and sedimentation. The pioneer work in isostatic investigation in the United States was done by John F. Hayford and his associates of the United States Coast and Geodetic Survey. Wegener's theory may also be classed as an isostatic theory.

Pratt considered the earth's crust to be made up of prisms of equal mass and equal cross-section, but of different densities and different thicknesses. The blocks are considered as extending downward to the zone of compensation and the lighter blocks as standing at greater heights as illustrated in Figure 1. The Airy conception of isostasy, or Roots of Mountains principle

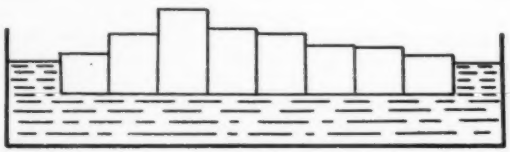

FIG. 1.—An illustration of isostasy according to Pratt. The blocks of different metals have the same cross-section and the same mass but different densities. The blocks are floating in mercury. Since they are of the same mass, each displaces the same amount of mercury and sinks to the same depth. The upper surfaces of the blocks stand at different heights, the lighter ones standing higher.

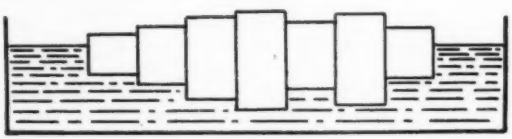

FIG. 2.—An illustration of isostasy according to Airy. The blocks have the same cross-section and the same density, but differ in mass. Since they differ in mass, they displace different amounts of mercury and extend to different heights and depths.

is illustrated in Figure 2. The Wegener idea of isostasy postulates that the continental crustal material is present only under the continents and islands, while Pratt and Airy consider it to extend under the oceans. Bowie concludes that the Pratt idea is the most logical and bases his conclusions on it.

The theory of isostasy was developed as follows. Geodetic surveyors found that plumb lines were deflected toward adjacent topographic elevations. In calculating the attraction of these land masses, it was found that

the deflections were much less than they should have been according to the calculations. Hayford and his associates computed the attractive effect of irregularities of the earth's surface on the plumb line at several hundred triangulation stations, considering all mountain masses and ocean basins within 2,564 miles of each station. These results and the methods used are described in "The Figure of the Earth and Isostasy," U. S. Coast and Geodetic Survey, 1909. It was concluded that there was a deficiency of density in the material under the mountainous regions and an excess of density under the ocean basins which nearly compensated for the deflection due to topography. It was found that the observed values of gravity tended to be less in mountainous regions and greater in coastal regions. This was attributed to deficiency of density under the mountainous regions.

Observations of the intensity of gravity at sea were made by Dr. Meinesz of the Dutch Geodetic Commission. The observations were made on a submarine which was submerged during the observations. The gravity values over the ocean give anomalies comparable in size with those obtained on land. "The anomalies have both positive and negative signs, thus indicating that the crust under the sea as a whole is neither extra light nor heavy."

The corrections for isostatic compensation thus computed were applied to the deflections of the vertical and the values of gravity. The deflection anomalies were on an average reduced to 10 per cent of what they would be if there were no isostatic compensation, and the average gravity anomaly to 10 to 15 per cent of what it would be on the rigid earth hypothesis. It is stated that the value of gravity can be computed at any given station with considerable accuracy by using isostatic computation of the effect of topography and compensation.

The figure of the earth is discussed in considerable detail. The geoid is the form which would be taken by the surface of the ocean undisturbed by meteorological conditions and the tidal forces of the sun and moon. The position of the water in sea-level canals over the continents would approximate the geoid. The geoid approximates a spheroid but rises above the spheroid about 19 meters in the United States and falls below the spheroid over the ocean depths. Plumb lines hang perpendicular to the geoid surface. The geoid calculated by isostatic methods is larger than according to previous calculations.

Bowie concludes that mountains and ocean basins are the result respectively of deficiency and excess of density of the crustal material. A change in density due to change in temperature, or a shifting of material due to erosion and sedimentation will upset this equilibrium and gravitation will cause a restoration of this equilibrium by a yielding of the earth's crust, which is considered very weak.

Bowie quotes Nansen, who has concluded that there was isostatic adjustment in Scandinavia due to the melting of the ice sheets.

Bowie states that the isostatic theory may now be called the isostatic principle. He says that if the geological field data conflict with isostasy, the apparent discrepancy is due to misinterpretation of the geological data and that geological data must be so interpreted as to harmonize with the established principle of isostasy, which requires an exceedingly weak crust.

A large part of the book is taken up with discussion of geological theories. Bowie concludes that the ocean depths were formerly mountains which sank due to erosion and cooling.

He also concludes that coral islands would sink under the accumulating coral and says, "Coral islands should present a fruitful field for research now that isostasy is established."

The entire earth may be affected by a zone of sedimentation. The deposition of sediment will raise the level of the sea, thereby increasing the load on the sea bottom, which will cause small adjustments of all the continents.

Stations on the pre-Cambrian tend to have large values of gravity and stations on the Cenozoic tend to have values below the average. Bowie considers that since isostasy is established, these areas must be in isostatic equilibrium and that the apparent discrepancies are due respectively to abnormally heavy and abnormally light materials at the surface which are compensated in depth.

The values of gravity tend to be greater over anticlines due to the denser materials being brought nearer to the surface.

It is stated that when a sedimentary area is uplifted, block faulting takes place if the outer layers of the crust are strong and rigid. If the outer layers of the crust are weak, they will arch upward. There would be a tendency for the weak beds to slump laterally, forming parallel ridges. Bowie supposes that this slumping would take place at a depth of about a mile or more.

Bowie concludes that earthquakes are caused by isostatic adjustments in the weak crust of the earth. He says that had the geodesists not proved the weakness of the earth's crust, the seismologists probably would have proved it somewhat later.

The values of gravity on volcanic islands tend to be too great due to the presence of material of abnormally great density near the surface. On the lava fields of the United States, the gravity anomalies are small. There has been merely a transfer of material from below the surface to the surface without an increase in the mass of the prism. Bowie concludes that volcanism originates at comparatively shallow depths. He says, "Volcanism is now receiving much attention and, with the principle of isostasy established, it should be possible to make great progress in that branch of geophysics.

Bowie discusses and rejects the contraction theory and concludes that forces causing uplift are vertical with horizontal movements incidental except in the sub-crustal matter. He quotes several authors who consider the southern Rockies to have been uplifted by vertical forces. He then says that most of the writers consider the uplift as the result of compressive stresses, but that lack of space prevents quoting them. He also disagrees with Chamberlin's hypothesis.

Bowie proposes the following theory to account for earth deformation. He postulates that the earth's surface was irregular at the beginning of the sedimentary age. Water collected in the hollows and precipitation of moisture caused erosion and transportation of sediments which were deposited in the water at the margins of the seas. The crust then sank beneath these sediments, the rocks involved in this sinking descended into hotter portions of the earth and their temperatures slowly increased. This increase of temper-

ature caused an expansion which resulted in a decrease of density. Due to the decrease of density, isostatic adjustment would cause these rocks to rise and become a zone of erosion. The areas of erosion would rise due to unloading. This rising would bring the rocks into cooler zones causing cooling with consequent shrinkage and increase of density which would cause them to sink. According to this theory, any given area may be alternately an area of erosion and an area of deposition. Bowie states that the strong point of this theory is that it apparently does no violence to the established principle of isostasy.

The reviewer wishes to offer the following comments.

One of the most striking features of this book is the large number of assumptions used in developing the various theories.

Bowie quotes Reid as saying that isostasy could not be proved by geologic observations but only by geodetic data in the form of deflections of the vertical and values of gravity.

The theory of isostasy hinges on the accuracy of the calculations of what the deflection of the plumb line ought to be. These calculations involve estimates of the mean elevation of large areas which have never been mapped topographically. They involve an estimate of the average density of the surface rocks of the earth, and this average is used indiscriminately for pre-Cambrian and for Tertiary and for all other areas. These calculations also involve a constant which is based on the assumption that the earth is a sphere of which the radius is 3,960 miles, which is inexact. The calculations of the topographic deflection involve so many approximations and assumptions that their precision is open to question.

In determining the gravity anomalies, a calculation is made of the theoretical value of gravity at sea-level at the station in question. The formula used involves the value of gravity at the equator, the latitude of the station, and constants dependent on the form of the earth. In the Faye Method, the observed value of gravity was reduced to sea-level by a formula involving an estimate of the average density of the rocks above sea-level, and an estimate of the mean elevation of the area about the station. Thus the derived anomaly was the difference between two computed values. Bowie corrects the calculated value of gravity at sea-level by the formula -0.0003086 H, where H is the altitude in meters, and thus compares the computed value with the observed value. The formula for the variation of gravity with altitude involves the altitude of the station above sea-level and also the radius of the earth. Since the radius of the earth varies with the latitude, the practise of reducing the formula to a constant times the altitude and using the formula for all latitudes, obviously introduces some error. The isostasists note that the greatest anomalies are found at mountain stations and accordingly make isostatic corrections. It is also true that the greater the amount of the correction for altitude, the greater the anomaly.

Bowie refers repeatedly to the excess of density which causes the depression of the crust under the ocean basins. He concludes from the observations of Meinesz that "the crust under the sea as a whole is neither extra light nor heavy." These statements are contradictory.

The gravity data obtained on the pre-Cambrian areas indicate an excess

of density in those areas. The assumption that lighter material exists below these pre-Cambrian areas is contrary to our knowledge of geology, which indicates rather that density increases downward. From the geological standpoint, it is more reasonable to believe that these areas are not in a state of isostatic equilibrium.

In postulating that sinking rocks will be heated and expand, the isostasists fail to consider that increased heat and pressure will cause recrystallization and increase of density. Rocks are compressible under great pressure. Both of these factors will oppose Bowie's process. We are uncertain as to the behavior of the coefficient of expansion under great heat and pressure.

Vertical movements of adjacent prisms of the earth's crust can only cause tension phenomena at the surface. All field observations and experimental data indicate that the greater part of the structural phenomena of the earth are due to compressive forces. Reid's statement quoted above is an admission that the study of geologic structure does not indicate isostatic adjustments. It appears, therefore, that the major causes of earth deformation are other than isostatic adjustments.

The fact that the earth is so nearly spherical in form indicates a tendency toward isostatic equilibrium. The gravity data on pre-Cambrian areas, and Bowie's statement of Meinesz' results would indicate that this state of equilibrium is not as perfect as the isostasists would have us believe. Our field observations and the experiments of Adams indicate a considerable degree of rigidity in the crust rather than the weakness attributed to it by the isostasists. It is probable that erosion and transportation of large amounts of sediment would affect regional diastrophism as outlined by Barrell and Willis, but the isostasists have failed to prove that isostatic adjustments are the major cause of earth deformation.

LYNDON L. FOLEY

TULSA, OKLAHOMA
December, 1927

The Petroleum and Allied Industries. By JAMES KEWLEY. Baillière, Tindall and Cox, London, 1922. Demy 8vo. x + 302 pp.; 43 figs. Price, 12 s. 6 d.

In this book the attempt is made to cover the entire field of petroleum, making it impossible to give information that is instructive. The information given is much too elementary for the informed reader and much too brief and general in scope to be of help to the uninformed. Many important processes and operations are mentioned, but clear and concise descriptive and informative material is lacking, though the book contains many references indicating where the information may be found. The section on shales and refining has been well written and gives the reader a good conception of the different products made. The methods of refining are not modern, nor are they treated from the scientific standpoint.

The book is divided into nine parts, the first of which covers the terminology, history, chemistry, geology, and theories of origin of petroleum. The chapters are brief, information very general, chemistry non-technical, theories not definite, and citations of references incomplete.

Part II, "Natural Gas." Little mention is made of the composition of natural gas, and its uses. The references are good but the contents brief.

Part III, "Crude Petroleum." The information on the occurrence of crude oil is misleading and indefinite. Mining is not mentioned except in the title. Mention of the operations of drilling, storage, transportation, and dehydration are made but very briefly described.

Part IV, "Crude Oils Produced by the Distillation of Shales, Coals, Lignites and the Like." No information is given on the important subject of the mining of shales. The chapter on retorting is well written and of interest.

Parts V and VI, "Natural Solid and Semi-Solid Bitumens and Allied Substances." The classification of the bitumens, applications, and mineral waxes are fair in information but brief in subject matter.

Part VII, "The Working Up of Crude Oils." The methods described are not modern, the information very general but of interest. The important subject of cracking receives little attention.

Part VIII. The information is very general but interesting. The numerous subjects covered are well written and references well chosen.

Part IX, "The Testing of Petroleum Products." No actual information is given, but references indicate where this information may be found.

R. C. BECKSTROM

COLORADO SCHOOL OF MINES
GOLDEN, COLORADO
December, 1927

RECENT PUBLICATIONS

COLORADO

Geology and Natural Resources of Colorado, by Russell D. George. Volume 1 of the *University of Colorado Semi-Centennial Series*, Boulder, Colorado, 1927. xv + 228 pp., illus. Price, $2.00.

GENERAL

"Fifty Years' Progress in Geology," (1876-1926), edited by Edward Bennett Mathews. Contains a chapter on "Fifty Years of Petroleum Geology," by D. W. Ohern. *The Johns Hopkins University Studies in Geology No. 8*, 1927. The Johns Hopkins Press, Baltimore, Maryland. 161 pp. Paper. Price, $1.50.

THE ASSOCIATION LIBRARY

Headquarters acknowledges library accessions:

CANADA

From the Geological Survey of Canada:

"Arsenic-bearing Deposits in Canada," by M. E. Hurst
Summary Report, 1926, Part A

Summary Report, 1926, Part C. Contains "Prospects for Petroleum in Lake Ainslie District, Cape Breton Island, etc.," by W. A. Bell. Also "Deep Borings in Ontario and Maritime Provinces," by E. D. Ingall

MEXICO

From W. Storrs Cole:

"A Foraminiferal Fauna from the Guayabal Formation in Mexico," Vol. 14, No. 51 (December, 1927), *Bulletins of American Paleontology*

ROUMANIA

From the University of Cluj, Roumania (through Professor I. P. Voitesti):

Revista Muzeului Geologic-Mineralogic al Universitatie din Cluj, Vol. 1, No. 1 (1924), contains "Review of the Occurrence of Petroleum," by I. P. Voitesti; No. 2 (1926); and Vol. 2, No. 1 (1927)

THE ASSOCIATION ROUND TABLE

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The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant).

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Memorial

CONRAD K. BONTZ

The news has just been received of the death at Iquitos, Peru, on September 20, 1927, of Conrad K. Bontz, from blood poisoning resulting from an accidental injury. At the time of his death, Mr. Bontz was in charge of a party engaged in geological exploration work in eastern Peru for the Standard Oil Company of New Jersey.

Mr. Bontz was born in Edenville, California, in 1894, and received his early training in Stanford University, graduating in 1919. His first geologic work was with the Shell Company of California, in development work at Coalinga.

After a short period of this work, he evinced a keen interest in foreign geological explorations in the more unsettled and unknown parts of the world. He was naturally endowed with a temperament and a disposition admirably suited to this type of pioneering. Although always averse to writing, his work, his opinions, and his abilities were held in high regard by those geologists with whom he came in contact in foreign fields.

His first foreign experience was in the employment of the Sinclair Exploration Company in Dilly, Timor, East Indies. Upon the completion of that work in 1922, he joined the staff of the Standard Oil Company of California in South America, in the Argentine. Returning to the United States in 1924, he spent a few months in geological work in the Rocky Mountains, but a desire for foreign work took him again abroad for this company for service in Colombia and Venezuela. Leaving the staff of the Standard Oil of California early in 1926, he entered the employ of the Standard Oil of New Jersey to take charge of a party to carry on geological work in eastern Peru.

HENRY J. HAWLEY

SAN FRANCISCO, CALIFORNIA
December, 1927

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

ALEXANDER DEUSSEN has resigned his position as vice-president of the Marland Oil Company of Texas at Houston.

C. R. MCCOLLOM, chief geologist of the Union Oil Company of California, resigned his connection with that company January 1. His address is now 452-53 Roosevelt Building, Los Angeles, California.

DESAIX B. MYERS has been appointed chief geologist of the Union Oil Company of California, at Los Angeles.

W. J. MILLARD resigned from the Trinidad Oil Fields, Inc., and returned to the United States last December. His address is 227 Lynch Building, Tulsa, Oklahoma.

JOHN H. WILSON has resigned as acting division geologist in charge of Mexican work for the Pan American Petroleum & Transport Company and has accepted a position as assistant professor of geophysics at the Colorado School of Mines.

A. I. LEVORSEN, recently chief geologist for the Philmack Company, of Tulsa, Oklahoma, became chief geologist for the Independent Oil & Gas Company last December, following purchase of the Philmack properties by the Independent.

J. V. HOWELL, formerly in charge of geological work for the Marland Oil Company at Amarillo, Texas, and more recently studying conditions in Canada, is now located with the company at Ponca City, Oklahoma.

G. L. ELLIS resigned his geological position with Snowden & McSweeney Company at Tulsa, Oklahoma, last December.

A division of production engineering was created by the American Petroleum Institute at Chicago last December. The officers of the new division are: JOHN SUMAN, chairman; T. E. SWIGART, vice-chairman; CARL YOUNG, acting secretary; regional chairmen, FRED E. WOOD, Rocky Mountain district, A. C. RUBEL, California district, C. D. WATSON, Mid-Continent district, E. O. BENNETT, Texas-Louisiana district, and FRANK M. BREWSTER, Eastern district.

S. SPENCER NYE has left Roswell, New Mexico, and is engaged in groundwater investigations in twelve counties in the Gulf Coast district of Texas. Mr. Nye's temporary address is U. S. Geological Survey, Austin, Texas.

FRANCIS DE LOYS, of Los Angeles, California, is now geological adviser to the Turkish Petroleum Company, Ltd., and in charge of the geological department, with headquarters in London.

E. RUSSELL LLOYD, recently with the Roxana Petroleum Corporation at Roswell, New Mexico, has returned to Denver, Colorado. His address is 1104 First National Bank Building.

RUSSELL C. CONKLING, of the Roxana Petroleum Corporation, has moved from San Angelo, Texas, to Carlsbad, New Mexico.

B. COLEMAN RENICK has resigned from his position with the Roxana Petroleum Corporation at Palestine, Texas.

W. GRANT BLANCHARD, formerly stationed at Denver, Colorado, has been transferred to Texas by the Marland Oil Company.

A. S. MCCULLOUGH, of the Twin State Oil Company at Los Angeles, California, has moved to Clifton, Greene County, Ohio.

The West Texas Geological Society held its regular annual meeting at the St. Angelus Hotel, San Angelo, Texas, last December and elected the following officers: president, EDGAR KRAUS, chief geologist of west Texas for the Atlantic Oil Producing Company; vice-president, C. D. VERTREES, in charge of the subsurface laboratories of west Texas for Marland Oil Company; and secretary-treasurer, E. C. EDWARDS, geologist for The Exploration Company of Texas. W. R. CALVERT, independent geologist of Del Rio, Texas, gave an address on the geology of Val Verde County and adjacent area.

GEORGE STEINER, of Houston, Texas, has finished a year's torsion balance survey in southern Louisiana. Mr. Steiner is now in Europe for a three months' stay of study, business, and pleasure. He may be reached by cable "Geodesia Steiner Budapest" or by mail in care of the Eotvos Geophysical Institute, Budapest, Hungary.

G. R. BOYLE sailed last December for Maracaibo, Venezuela, where he will be established as geologist for the Rio Palmar Oil Company.

W. A. CLARK, JR., recently with the Indian Territory Illuminating Oil Company of Bartlesville, Oklahoma, has been transferred to the Delmar Oil Company at San Angelo, Texas.

ROBERT S. BURG, 1616 Hillcrest Avenue, Fort Worth, Texas, has recovered to such an extent from a fractured spine and other injuries sustained while engaged in geological work in Texas last May, that he expects to resume field work this spring.

MR. and MRS. WALTER W. LARSH announce the arrival of a daughter, Doris Anne, on December 28. Mr. Larsh is geologist for the Dixie Oil Company with headquarters at Wichita, Kansas.

The American Institute of Mining and Metallurgical Engineers holds its annual meeting in New York City, February 20-23. Feature of particular interest to petroleum geologists are a symposium on geophysical prospecting and the sessions of the petroleum division.

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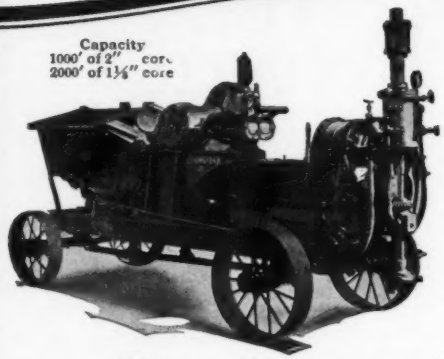

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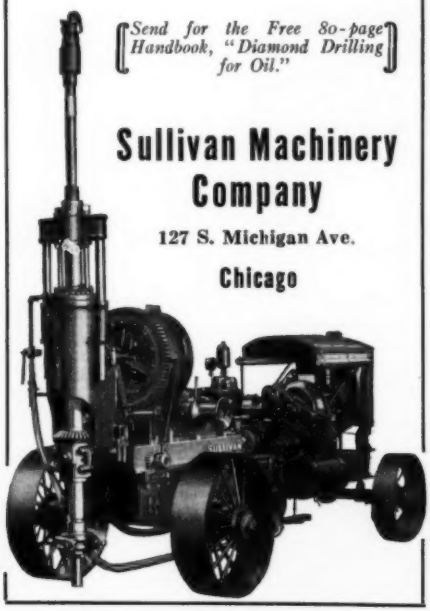

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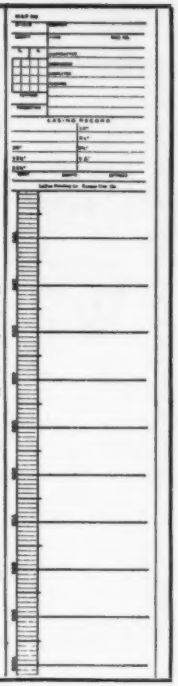

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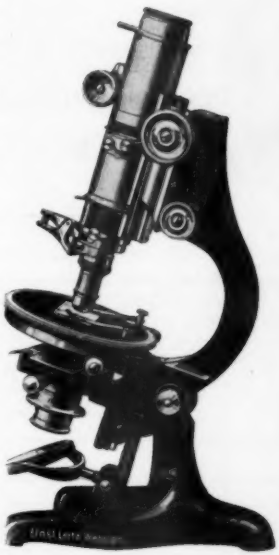

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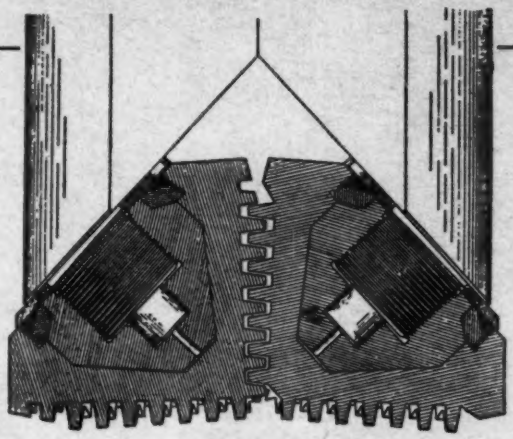

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